Cosmic Origins (COR) Strategic Technology Development Portfolio

December 2015

Current COR Technology Development Portfolio

Funding Source	Technology Development Title	Principal Investigator	Org	Start Year	TRL	Science Area	Tech Area
SAT2011	Kinetic Inductance Detector Imaging Arrays for Far-Infrared Astrophysics	Jonas Zmuidzinas	JPL	FY2013, 3 years	3	Far-IR	Detectors
SAT2011	Ultraviolet coatings, materials and processes for advanced telescope optics	Kunjithapatham Balasubramanian	JPL	FY2013, 3 years	3	UV	Optical Coatings
SAT2012	A Far-Infrared Heterodyne Array Receiver for CII and OI Mapping	Imran Mehdi	JPL	FY2014, 3 years	4	Far-IR	Detectors
SAT2012	Deployment of Digital Micromirror Device (DMD) Arrays For Use In Future Space Missions	Zoran Ninkov	RIT	FY2014, 2 years	4	UV	Spectroscopy
SAT2012 & SAT2010	Advanced Mirror Technology Development Phase 2	Phil Stahl	MSFC	FY2014, 3 years FY2012, 3 years	3	UVOIR	Optics
SAT2014	Raising the Technology Readiness Level of 4.7-THz local oscillators	Qing Hu	MIT	FY2016, 3 years	3	Far-IR	Detectors
SAT2014	Building a Better ALD - use of Plasma Enhanced ALD to Construct Efficient Interference Filters for the FUV	Paul Scowen	ASU	FY2016, 3 years	3	UV	Optical Coatings
SAT2014 & SAT2010	Development of Large Area (100x100 mm) photon counting UV detectors	John Vallerga	UCB	FY2016, 2 years	4	UV	Detectors
SAT2014 & SAT2011	Advanced FUVUV/Visible Photon Counting and Ultralow Noise Detectors	Shouleh Nikzad	JPL	FY2016, 3 years	3 - 4	UVOIR	Detectors

Kinetic Inductance Detector Arrays for Far-IR Astrophysics

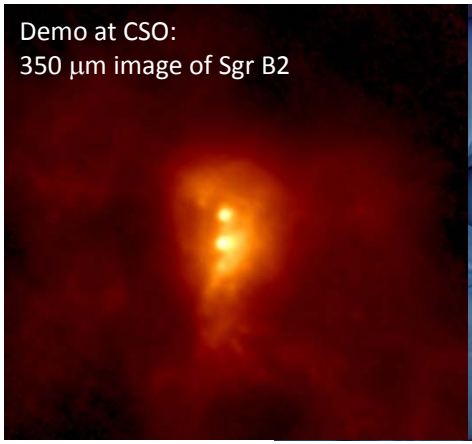
PI: Jonas Zmuidzinas/Caltech

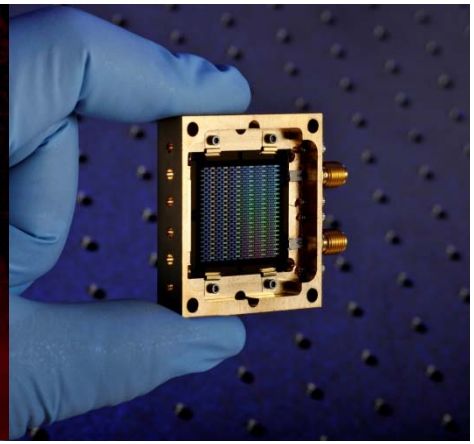
Objectives and Key Challenges:

- Half of the electromagnetic energy emitted since the big bang lies in the far-IR. Large-format far-IR imaging arrays are needed to study galaxy formation and evolution, and star formation in our galaxy and nearby galaxies. Polarization-sensitive arrays can provide critical information on the role of magnetic fields.
- We will develop and demonstrate far-IR arrays for these applications

Significance of Work:

- Far-IR arrays are in high demand but are difficult to fabricate, and therefore expensive and in short supply. Our solution is to use titanium nitride (TiN) and aluminum absorber-coupled, frequency-multiplexed kinetic inductance detectors.





Approach:

- Raise the TRL of these detectors so investigators may confidently propose them for a variety of instruments:
  - Ground telescope demo, 350 µm, 3×10^{-16} W Hz$^{-1/2}$
  - Lab demo for space, 90 µm, 5×10^{-19} W Hz$^{-1/2}$

Key Collaborators:

- Goutam Chattopadhyay, Peter Day, Darren Dowell, and Rick Leduc (JPL)
- Chris McKenney (JPL/NIST)
- Pradeep Bhupathi, Matt Holllister, and Attila Kovacs (Caltech)

Current Funded Period of Performance:

Mar 2013 – Dec 2016 (no-cost extension after original 2-year project)

Recent Accomplishments:

- ✓ Successful 350 and 850 µm demos on telescope (350 µm image above)
- ✓ Photon-noise-limited 350 µm lens-coupled arrays
- ✓ Low-cost, high-yield multiplexing of 500-pixel arrays
- ✓ Process improvement (high yield) in aluminum KID for space-background operation
- ✓ Demonstration of new chirped readout technique at telescope

Next Milestone:

- Optical tests of space-sensitivity arrays (through end of project)

Applications:

- Future space missions, *e.g.*, Far IR Surveyor
- Suborbital projects: SOFIA instruments, and balloon payloads
- Cameras and spectrometers for ground-based telescopes
- CMB arrays, now under development at Columbia University

TRL_{In} = 3 $TRL_{PI\text{-}Asserted}$ = 3, 6 TRL_{Target} = 4-6

Ultraviolet Coatings, Materials and Processes for Advanced Telescope Optics

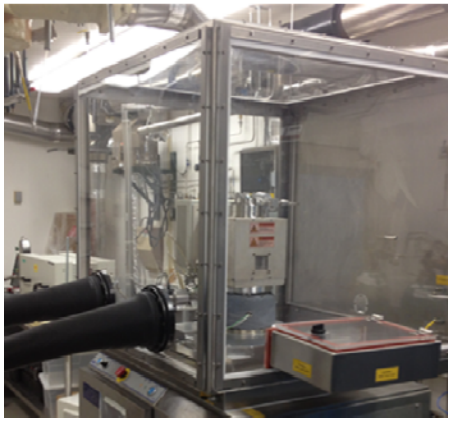
PI: Bala K. Balasubramanian/JPL

Objectives and Key Challenges:

- "Development of UV coatings with high reflectivity (>90-95%), high uniformity (<1-0.1%), and wide bandpasses (~100 nm to 300-1000 nm)" is a major technical challenge as much as it is a key requirement for cosmic origins program and for exoplanet exploration program. This project aims to address this key challenge and develop feasible technical solutions.

Significance of Work:

- Materials and process technology are the main challenges. Improvements in existing technology base and significant innovations in coating technology such as Atomic Layer Deposition will be developed.



ALD chamber at JPL

1.2m coating chamber at Zecoat Corp

Approach:

- A set of experimental data developed with MgF_2, AlF_3 and LiF protected Al mirrors in the wavelength range 100 to 1000 nm for a comprehensive base of measured data to enable full scale developments with chosen materials and processes.
- Enhanced coating processes including Atomic Layer Deposition (ALD) will be studied.

Key Collaborators:

- Stuart Shaklan (JPL), Nasrat Raouf (JPL), Shouleh Nikzad (JPL), John Hennessy (JPL)
- Manuel Quijada (GSFC) FY15.
- Paul Scowen (ASU), James Green (Univ of Colo) FY14.

Current Funded Period of Performance:

- Jan 2013 – Dec 2015

Recent Accomplishments:

- ✓ A coating chamber has been upgraded with sources, temperature controllers and other monitors to produce coatings of various materials. Measurement tools are also established now at JPL and at GSFC.
- ✓ Initial samples of protected Al with LiF and AlF3 have been produced and measured with encouraging results for further improvements
- ✓ ALD coating process tools and process for MgF2 and AlF3 have been developed and are being optimized
- ✓ Produced & tested mirror coupons representing a meter-class mirror (2015)

Next Milestones:

- Reach ~ 90% reflectivity in the 100 to 200nm band (2015)

Application:

- The technology to enable future astrophysics and exoplanet missions that aim to capture key spectral features from far UV to near infra red.
- ATLAST, LUVOIR, HDST, EXEP Missions

TRLin = 3 ***TRLcurrent est. by PI = 3*** ***TRLtarget = 5***

A Far-Infrared Heterodyne Array Receiver for CII and OI Mapping

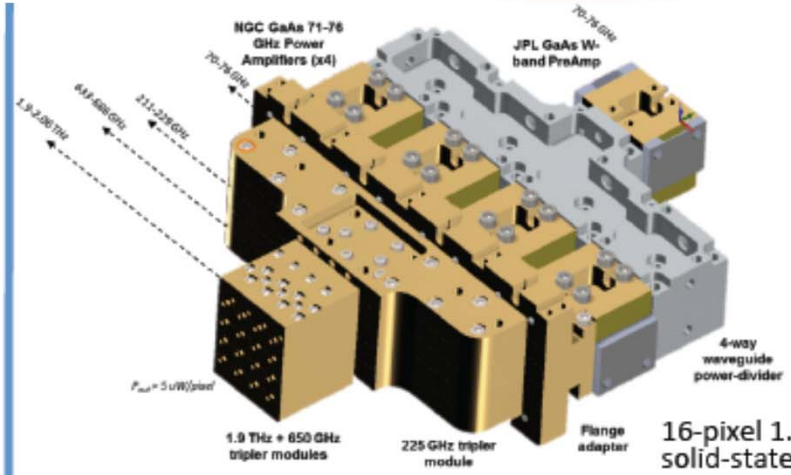
PI: Iman Mehdi/JPL

Objectives & Key Challenges:

- Heterodyne technology is necessary to answer fundamental questions such as how do stars form? How do circumstellar disks evolve and form planetary systems? What controls the mass-energy-chemical cycles within galaxies?
- We will develop a 16-pixel heterodyne receiver system to cover both the C+ and the O+ lines.

Significance of Work:

- Proposed work will advance the TRL of array receivers so that they can be deployed on airborne platforms such as SOFIA or future suborbital and space missions



16-pixel 1.9 THz all solid-state LO source

Approach:

- Use JPL-developed membrane diode process to construct tunable sources in the 1.9 - 2.06 THz range
- Use novel, waveguide-based, active-device, power-combining schemes to enhance power at these frequencies
- Design and build compact, silicon, micro-machined housing for HEB mixer chips
- Use CMOS technology for back-ends/synthesizer
- Characterize and test multi-pixel receivers to validate stability and field performance

Key Collaborators:

- Paul Goldsmith (Science Lead), Jon Kawamura, Jose Siles, Choonsup Lee, and Goutam Chattopadhyay (JPL)
- Frank Chang (UCLA)
- Sander Weinreb (Caltech)

Development Period:

- October 2013 – September 2016

Recent Accomplishments:

✓ Completed system architecture design and interface controls
✓ Designed mixer devices
✓ Designed multiplier devices
✓ Fabricated mixer devices
✓ Fabricate multiplier devices
✓ Demonstrated 4 pixel LO source at 1.9 THz
✓ Demonstrated 4-pixel receiver at 1.9 THz

Next Milestones:

- Assemble 4-pixel receiver with CMOS backend
- Characterize receiver sensitivity and stability
- Design 16-pixel receiver components
- Fabricate 16-pixel receiver components
- Assemble and test 16-pixel receiver

$TRL_{In} = 4$ $TRL_{Current} = 4$ $TRL_{Target} = 5$

Development of Digital Micro-Mirror Device Arrays for Use in Future Space Missions

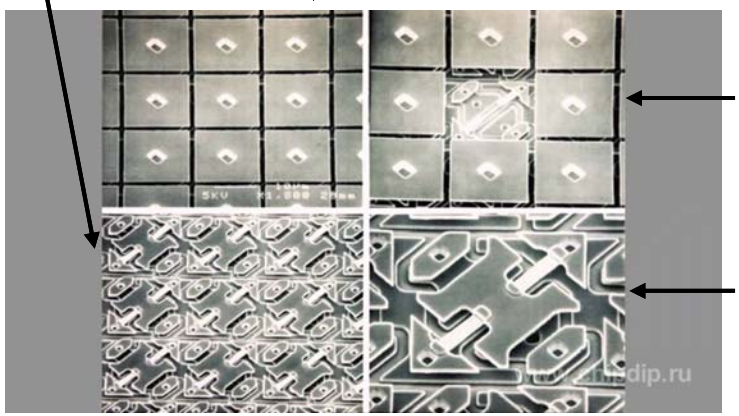
PI: Zoran Ninkov/Rochester Institute of Technology

Objectives and Key Challenges:

- There is a need for a technology to allow for selection of targets in a field of view that can be input to an imaging spectrometer for use in remote sensing and astronomy.
- We are looking to modify and develop Digital Micromirror Devices (DMD) for this application.

Significance of Work:

- Existing DMDs need to have the commercial windows replaced with appropriate windows for the scientific application desired.



Approach:

- Use available 0.7 XGA DMD devices to develop window removal procedures and then replace delivered window with a hermetically sealed UV transmissive one of Magnesium Fluoride, HEM Sapphire and fused silica. Test and evaluate such devices and also Cinema DMDs.

Key Collaborators:

- Sally Heap, Manuel Quijada (NASA/GSFC)
- Massimo Robberto (STScI)
- Alan Raisanen (RIT)
- Jonny Pellish (NASA GSFC)
- Tim Schwartz (NASA GSFC)

Current Funded Period of Performance:

- May 2014 – May 2016

Recent Accomplishments:

- 0.7 XGA DMD delivered and 1.2 D2K DMDs ordered.
- XGA devices re-windowed succesfullyMgF2.
- Heavy ion testing shows good results.
- Contrast measurements indicate high contrast.

Next Milestones:

- UV-test XGA DMD at GSFC (March 2015)
- Re-windowed DMDs from L-1 Technology (May 2015)
- Cinema DMD and electronics delivery (July 2015)

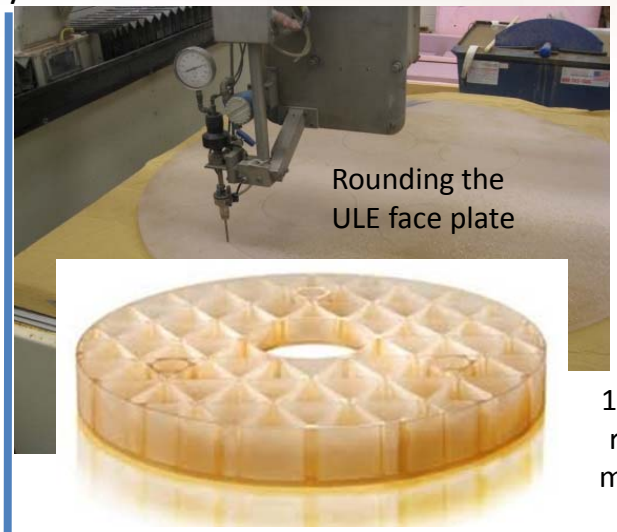
Application:

- Can be used in any hyper-spectral imaging mission.
- Galaxy Evolution Spectroscopic Explorer

$TRL_{In} = 4$ $TRL_{Current} = 4$ $TRL_{Target} = 5$

Advanced UVOIR Mirror Technology Development for Very Large Space Telescopes

PI: Phil Stahl/MSFC



1.2m Schott mirror ready for polish & mounting structure

Objectives and Key Challenges:

- Advance TRL of key technology challenges for the primary mirror of future large-aperture Cosmic Origins UVOIR space telescopes
- Include monolithic and segmented optics design paths
- Conduct prototype development, testing, and modeling
- Trace metrics to science mission error budget

Significance of Work:

- Deep-core manufacturing method enables 4-m class mirrors with a 20-30% lower cost and risk
- Design tools increase speed and reduce cost of trade studies
- Integrated modeling tools enable better definition of system and component engineering specifications

Approach:

- Science-driven systems engineering
- Mature technologies required to enable highest priority science and result in high-performance, low-cost, low-risk system
- Provide options to science community by developing technology enabling both monolithic- and segmented-aperture telescopes
- Mature technology in support of 2020 Decadal process

Key Collaborators:

- Dr. Scott Smith, Ron Eng, and Mike Effinger (MSFC)
- Bill Arnold (AI Solutions)
- Gary Mosier (GSFC)
- Dr. Marc Postman (STScI)
- Olivier Guyon (U of Arizona)
- Stuart Shaklan and John Krist (JPL)
- Al Ferland, Gary Matthews, and Rob Egerman (Harris)

Current Funded Period of Performance:

Sep 2011 – Dec 2016

Recent Accomplishments:

- ✓ Finalized 1.5-m design, traceable to 4 m, using A-Basis strength data
- ✓ Fabrication of ULE & Zerodur mirrors & support structure in-process
- ✓ Characterized 40-cm deep core with X-ray computed tomography
- ✓ Received approval for Arnold Mirror Modeler code distribution
- ✓ Developed thermal MTF modeling methodology
- ✓ TRL Board Assessment
- ✓ Published at SPIE O&P and Tech Days 2015

Next Milestones:

- Publish results
- Fabricate and assemble 1.5-m mirror substrate

Applications:

- Flagship optical missions; Explorer-type optical missions
- Department of Defense and commercial observations

TRL_{In} = 3 - 5+ $TRL_{Current}$ = 3 - 5+ TRL_{Target} = 3+ - 6

(values depend on specific technology)

Raising the Technology Readiness of 4.7-THz local oscillators

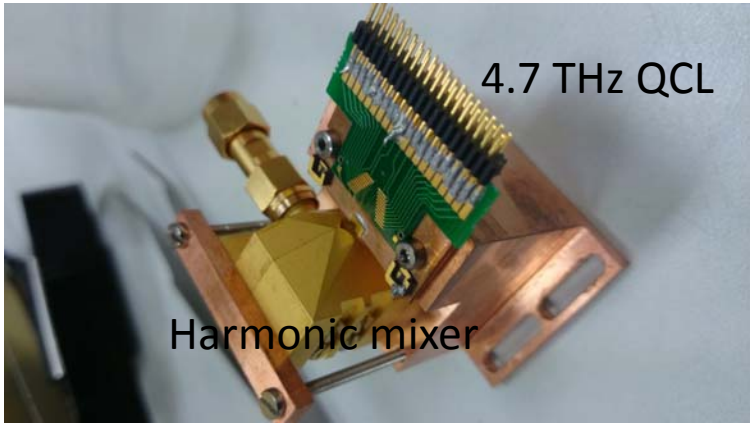
PI: Qing Hu/MIT

Objectives and Key Challenges:

- This project seeks to raise the TRL of 4.7-THz local oscillators based on THz quantum-cascade lasers.
- The key challenges are to increase the output power level from the current level of <1 mW to 5 mW, and to increase the operating temperature from a lab-demonstrated ~10 K to ~40 K that can be provided in a space-based or suborbital observatory.

Significance of Work:

- The 4.744 THz [OI] fine-structure line is the dominant cooling line of warm, dense, neutral atomic gas. Observation of this line will provide valuable information for studies of cosmic origins.
- This project will be important to the proposed GUSTO project.



Array of DFB lasers at ~4.7 THz. The harmonic mixer is used to phase lock the QCL LO.

Approach:

- Develop perfectly phase-matched 3rd-order DFB structures at 4.7 THz with robust single-mode operations with good beam patterns.
- Develop phase-matched 3rd-order DFB coupled with integrated antennae to increase the output power level to ~5 mW, and to increase the wall-plug power efficiency to 0.5%.

Key Collaborators:

- John L. Reno, Sandia
- J. R. Gao, SRON/Delft

Current Funded Period of Performance:

- March 1, 2016 – February 28, 2019

Recent Accomplishments:

- N/A

Next Milestones (by 2/28/2017):

- Complete the design of perfectly phase-matched 3rd-order DFB lasers aimed for ~4.7 THz.
- Develop a high-yield dry-etching process using ICP (inductive-coupled plasma) to achieve clean and smooth side walls with high aspect ratios.
- Grow ~3 MBE wafers based on improved QCL designs.
- Fabricate devices using a combination of dry and wet etching.

Application:

- GUSTO (The Gal/Xgal U/LDB Spectroscopic/Stratospheric THz Observatory)

*TRLin = **3*** *TRLcurrent = **3*** *TRLtarget = **5***

Building a Better ALD - use of Plasma Enhanced ALD to Construct Efficient Interference Filters for the FUV

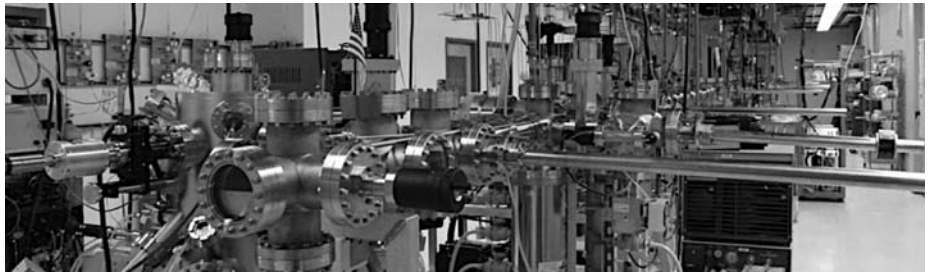
PI: Paul Scowen/Arizona State University

Objectives and Key Challenges:

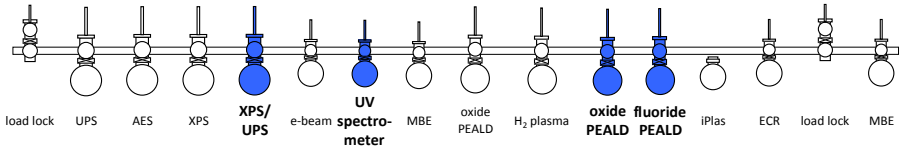
- Use a range of oxide and fluoride materials to build stable optical layers using PEALD to reduce adsorption, scattering and impurities
- Layers will be suitable for protective overcoats with high UV reflectivity and unprecedented uniformity (compared to thermal ALD)
- Development of single-chamber system to deposit metal oxide and dielectric layers without breaking vacuum

Significance of Work:

- To use the improved ALD capability to leverage innovative ultraviolet/optical filter construction



Integrated processing and characterization UHV chambers:



Approach:

- Development of existing PEALD system to a single-chamber model
- Demonstration of Al film deposition
- Demonstration of Fluoride deposition on top of Al films
- Demonstration of VUV reflectivity, uniformity and stability

Key Collaborators:

- Paul Scowen, Robert Nemanich, Brianna Eller, Franz Koeck, Hongbin Yu (ASU)
- Tom Mooney (Materion)
- Matt Beasley (Planetary Resources Inc.)

Current Funded Period of Performance:

- Dec 2015 through Nov 2018

Recent Accomplishments:

✓ Program just getting started, but designs for chambers and milestones and metrics have been defined

Next Milestones:

- Design and install in-situ VUV spectrometer to measure performance down to 120nm – calibrate performance using NIST-calibrated UV detector – June 2016
- Demonstrate deposition of Al films using PEALD and measure UV reflectivity – measure to accuracy better than 3% - December 2016
- Demonstration of the deposition of low-loss oxides on evaporated Al surfaces – provide usable surface for reflection below 190nm – September 2016

Application:

- LUVOIR / HDST / ATLAST

$TRL_{In} = 4$ $TRL_{PI\text{-}Asserted} = 4$ $TRL_{Target} = 5$

Cross Strip MCP Detector Systems for Spaceflight

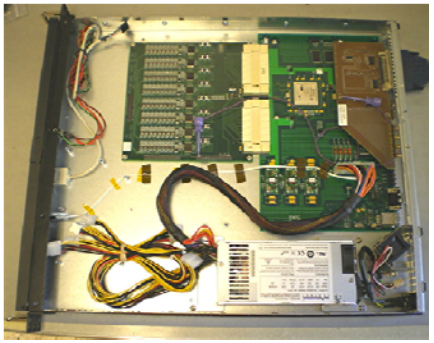
PI: John Vallerga/U.C. Berkeley

Description and Objectives:

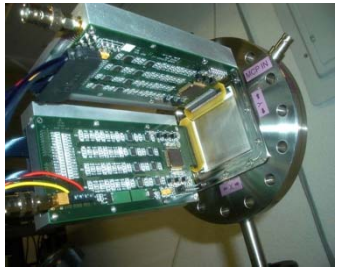
- Cross strip (XS) MCP photon counting UV detectors have achieved high spatial resolution (12µm) at low gain (500k) and high input flux (MHz) using laboratory electronics and decades old ASICs. We plan to develop new ASICs ("GRAPH") that improve this performance, which includes amps and ADCs in a small volume, mass and power package crucial for spaceflight and demonstrates its performance to TRL 6.

Key Challenge/Innovation:

- A new ASIC with amplifiers a factor of 5 faster yet with similar noise characteristics as existing amplifier ASIC
- GHz analog sampling and a low power ADC per channel
- FPGA control of ASIC chip(s)



Existing 19" rack mounted XS electronics



Two small, low mass, low power ASIC and FPGA boards qualified for flight

Approach:

- We will develop the ASIC in stages, by designing the four major subsystems (amplifier, GHz analog sampler, ADC and output multiplexor) using sophisticated simulation tools for CMOS processes. Small test runs of the more intricate and untested designs can be performed through shared access of CMOS foundry services to mitigate risk. We plan 2 runs of the full up GRAPH design (CSA preamp and "HalfGRAPH"). In parallel, we will design and construct an FPGA readout circuit for the ASIC as well as a 50mm XS MCP detector that can be qualified for flight use.

Key Collaborators:

- Prof. Gary Varner, U. Hawaii
- Dr. Oswald Siegmund, U.C. Berkeley

Development Period:

- May 1, 2012 – Apr 30, 2016

Accomplishments and Next Milestones:

- 50 mm detector design and fabrication complete
- Confirmed detector performance with PXS electronics
- Designed, fabricated and tested first half-GRAPH1 ASIC
- Design and fabrication of half-Graph ver2 - Dec 2014
- Successful Thermal test of detector (-30ºC to +55ºC) - Aug. 2014
- Successful Vibration test of detector (14.1 Grms) - Dec. 2014
- Fabrication and performance testing of CSA – Sept. 2015
- ASIC integration with control FPGA boards (Winter 2015)
- Environmental tests of Detector + ASICs (Spring 2016)

Applications:

- High performance UV(1-300nm) detector for astrophysics, planetary, solar, heliospheric, or aeronomy missions
- Particle or time of flight detector for space physics missions
- Neutron radiography/tomography for material science

TRLin = 4 ***TRLcurrent = 4*** ***TRLtarget = 6***

Advanced FUVUV/Visible Photon Counting and Ultralow Noise Detectors

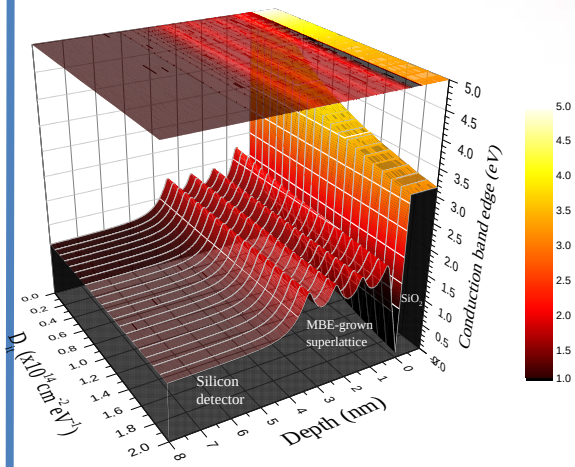
PI: Shouleh Nikzad/JPL

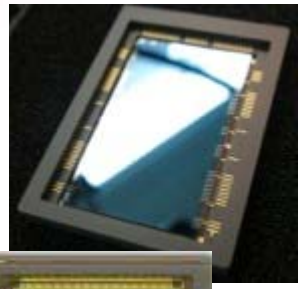
Objectives and Key Challenges:

- Objective Develop and advance TRL of solar blind, high efficiency, photon counting, and ultralow noise solid-state detectors esp. in FUV (λ < 200 nm).
- Key challenges: solar blind silicon, large format arrays, reliable and stable high response in the FUV

Significance of Work:

- Key innovation of work are: high and stable response in the ultraviolet through atomic level control of surface and interfaces; the breakthrough in rendering Si detectors with optimized in-band response and out of band rejection. Versatility with CMOS and CCD.





Approach:

- Fabricate & Process UV detectors by SuperLattice (SL) doping Electron Multiplying CCDs(EMCCDs) and ultralow noise CMOS wafers
- Develop multistack integrated solar blind filters using atomic layer deposition (ALD)
- Combine integrated SB filters and SL, with sCMOS and EMCCDs
- Characterize, and validate

Key Collaborators:

- Chris Martin, Caltech
- David Schiminovich, Columbia University
- Michael Hoenk, JPL
- e2v

Current Funded Period of Performance:

- December 2015 – December 2018

Recent Accomplishments:

✓ New task

Next Milestones:

- Procure two megapixel EMCCD wafers (Feb 2016)
- Procure sCMOS wafers (March 2016)
- Begin design of FUV integrated filters (July 2016)
- Process wafers by thinning and bonding (June 2016)

Application:

- Large UV/Optical/NIR Telescope
- Probes, Explorers

TRL_{In} = 3 $TRL_{PI\text{-}Asserted}$ = 3 TRL_{Target} = 4-5