Physics of the Cosmos (PCOS) Strategic Technology Development Portfolio

April 2015

Current PCOS Technology Development Portfolio

Funding Source	Technology Development Title	PI	Organization	TRL In	Current TRL	Start Year and Duration	Science Area
SAT2010	Directly-Deposited Blocking Filters for Imaging X-ray Detectors	M. Bautz	MIT	5	5	FY12, 4 years	X-ray
SAT2011	Demonstrating Enabling Technologies for the High-Resolution Imaging Spectrometer of the Next NASA X-ray Astronomy Mission	C. Kilbourne	GSFC	4	4	FY13, 3 years	X-ray
SAT2011	Colloid Microthruster Propellant Feed System for Gravitational-Wave Astrophysics Missions	J. Ziemer	JPL	3	4	FY13, 2 years	GW
SAT2011	Telescope for a Space-based Gravitational-Wave Mission	J. Livas	GSFC	3	3	FY13, 3 years	GW
SAT2011	Advanced Laser Frequency Stabilization Using Molecular Gases (co-funded with STMD)	J. Lipa	Stanford	3	3	FY13, 3 years	GW
SAT2012	Antenna-Coupled Superconducting Detectors for Cosmic Microwave Background Polarimetry	J. Bock	JPL	3	3	FY14, 2 years	Inflation
SAT2012	Demonstration of a TRL 5 Laser System for eLISA	J. Camp	GSFC	3	3	FY14, 2 years	GW
SAT2012	Phase Measurement System Development for Interferometric Gravitational-Wave Detectors	W. Klipstein	JPL	4	4	FY14, 3 years	GW
SAT2013 & SAT2010	Advanced Packaging for Critical Angle X-ray Transmission Gratings	M. Schattenburg	MIT	3	3	FY15, 2 years	X-ray
SAT2013 & APRA2011	Development of 0.5 Arc-second Adjustable Grazing Incidence X-ray Mirrors for the SMART-X Mission Concept	P. Reid	SAO	2	3	FY15, 3 years	X-ray
SAT2013 & SAT2010	Reflection Grating Modules: Alignment and Testing	R. McEntaffer	U. of Iowa	3	4	FY15, 2 years	X-ray
SAT2013 & SAT2011	Affordable and Lightweight High-Resolution Astronomical X-Ray Optics	W. Zhang	GSFC	3	4	FY15, 2 years	X-ray
SAT2013	Fast Event Recognition for the ATHENA Wide Field Imager	D. Burrows	PSU	3	3	FY15, 2 years	X-ray
SAT2013	Technology Development for an AC-Multiplexed Calorimeter for ATHENA	J. Ullom	NIST	3	3	FY15, 2 years	X-ray

Deposited Blocking Filters for X-ray Detectors

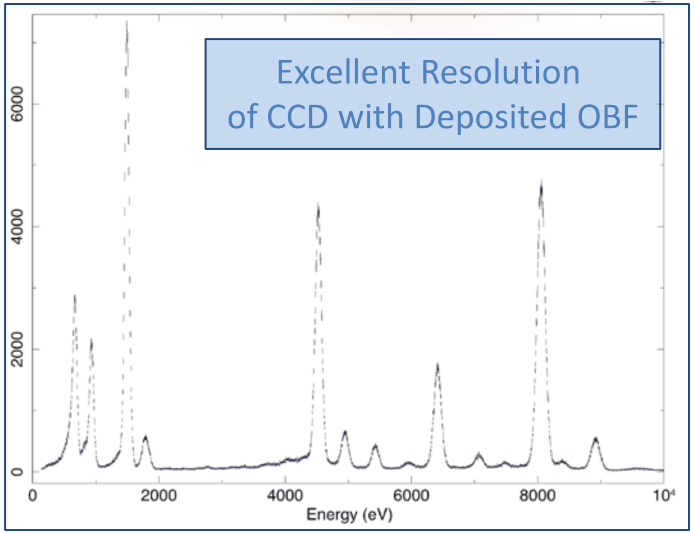
PI: Mark Bautz/MIT MKI

Objectives and Key Challenges:

- Silicon Imaging X-ray detectors require filters to block noise/background from UV and optical light
- Filters must be thin (<300 nm) to transmit X-rays
- State-of-the-art, free-standing filters use fragile, thin substrates
- Objective: deposit blocking filter directly on CCD X-ray detector, eliminating substrate

Significance of Work:

- Filter deposited on detector requires no fragile substrate
- Allows cheaper, more robust sensors (no vacuum housing!)
- Improves QE & makes larger focal planes practical
- Challenges:
- Deposit filter directly without compromising CCD performance
- Deposit sufficiently thin, uniform filters



Approach:

- Exploit existing stocks of (engineering grade/flight spare) X-ray CCD detectors at MIT Lincoln Laboratory
- Screen, thin, passivate, package & apply filters to detectors
- Filter is Al with AlO_2 cap
- Start thick (220 nm Al), get progressively thinner
- Use existing MIT facilities for X-ray characterization
- Use existing & upgraded facilities for optical characterization

Key Collaborators:

- MIT Kavli Institute (Bautz, Kissel et al.)
- MIT Lincoln Laboratory (Suntharalingam, Ryu, Burke, O'Brien)

Current Funded Period of Performance:

Jul 1, 2012 – Jun 30, 2015

Recent Accomplishments:

- Tested devices with alternative back side treatment (10nm MBE vs. 20nm MBE of previous) and 70nm & 100nm thick Al OBF. Optical blocking as expected; OD7 pinhole fraction 0.5%; X-ray performance similar to 20nm MBE devices
- Identified leakage paths through CCD support wafer at long ($\lambda \gtrsim$1000nm) wavelength, with detection efficiency ~2.5%
    - Significant for REXIS (large visible-light flux)
- Developed underside coating as countermeasures for leakage:
    - Aluminum or 'Z307' paint; REXIS will fly 1 of these

Next Milestones:

- Support tests of REXIS flight CCDs/OBFs, achieve TRL-6

Application:

Every X-ray imaging or grating spectroscopy mission

- Explorers (Lobster, Arcus…)
- "Probes" (AEGIS, N_XGS, AXSIO, WFXT…)
- Flagship (Athena…)

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

Demonstrating Enabling Technologies for the High-Resolution Imaging Spectrometer of the Next NASA X-ray Mission

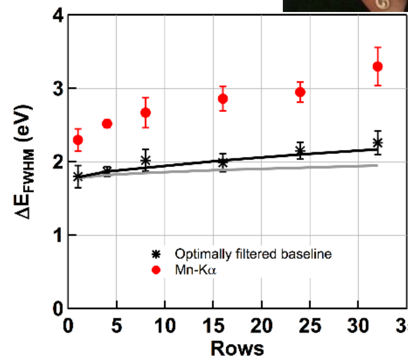
PI: Caroline Kilbourne NASA/GSFC

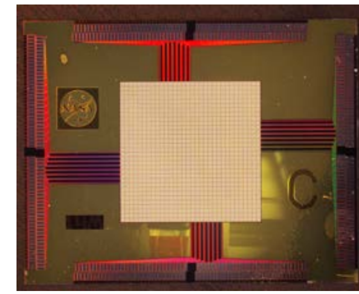
Objectives and Key Challenges:

- Developing large-format arrays of X-ray microcalorimeters & read-out, enabling next generation of high-resolution X-ray imaging spectrometers for astrophysics.
- Advance TRL of the key components of an X-ray microcalorimeter imaging spectrometer from TRL-4 to TRL-5, and to advance a number of important related technologies to at least TRL-4.

Significance of Work:

- Demonstrate multiplexed (3 columns x 32 rows) read-out of 96 different flight-like pixels on a 0.25 mm pitch in a 32x32 (or greater) array with > 95% of pixels achieving better than 3-eV resolution at 6 keV.





Energy resolution at 6 keV in 32 x 32 array with TDM multiplexed read-out of different numbers of rows.

Approach:

- Mo/Au TES thermometers with close-packed Bi/ Au thermalizing x-ray absorbers on a 0.25 mm pitch. Time-division multiplexed read-out.
- For point source array, fine-pitch (0.075 mm) pixels with Au absorbers.

Key Collaborators:

- Joel Ullom, Randy Doriese, Carl Reintsema – NIST
- Kent Irwin – Stanford
- Joseph Adams, Simon Bandler, Richard Kelley, Scott Porter, Stephen Smith - GSFC

Current Funded Period of Performance:

- October 1, 2012 – September 30, 2015
  - Program initially funded as 2-year program, rescheduled as 3-year program due to key participants' involvement with Astro-H

Recent Accomplishments:

- High-resolution spectroscopic capability demonstrated when reading out kilo-pixel array with two multiplexed columns from the array, each of which is multiplexing the read-out of 16 pixels (2/2014).
- Increased speed of read-out amplifier and digital feedback electronics, close to fulfilling the target specifications (12/2014).

Next Milestones:

- Will demonstrate 3x32 multiplexed read-out of standard pixels, and also multiplexed read-out of Hydras and small-pitch pixels (3/2015 – 9/2015).

Application:

- Potential contribution to the X-ray Integral Field Unit Instrument on ATHENA (Advanced Telescope for High ENergy Astrophysics)
- Japanese mission such as DIOS, or X-ray mission as follow-on to ASTRO-H.

*TRLin = **4*** *TRLcurrent est. by PI = **4.5*** *TRLtarget = **5***

Colloid Microthruster Propellant Feed System

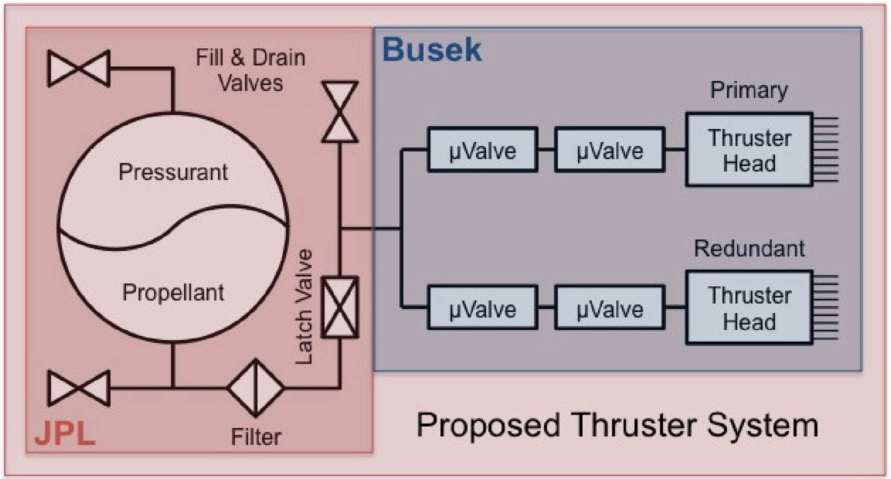
PI: John Ziemer/JPL

Objectives and Key Challenges:

- Replace the heavy (up to 15 kg) spring-loaded bellows design from ST7 with a light-weight pressurized diaphragm tank (≤1 kg)
  - O1: Design tank and feed system with full redundancy
  - O2: Design, fabricate, and test stainless steel diaphragm tank
- Use the new Busek Microvalve (Phase II SBIR and Phase IIe) to reduce complexity while providing redundancy
  - O3: Design, fabricate, and test new Busek Microvalves
  - O4: Integrate and test feed system components to TRL 5

Significance of Work:

- A new, flight-like, fully redundant, higher capacity colloid thruster feed system at TRL 5 can support any gravity wave observatory concept
- A clear path to TRL 6 once the mission and system are defined



Approach:

- Teaming arrangement between flight tank vendor Keystone, Busek for the Microvalve, and JPL to manage, perform I&T
- Use standard liquid-fed propulsion flight design guidelines and practices – the new technology is in the assembled pieces working together, not the propulsion engineering approach
- Four tasks related to each objective, plus a management task, each with a JPL expert lead
- Hold peer reviews at each meaningful milestone: requirements definition, design, and test

Key Collaborators:

- Busek Co., Inc. on Microvalve and systems engineering
- Keystone Engineering on flight-like tank manufacture and test
- JPL electric / chemical propulsion and flight propulsion groups

Current Funded Period of Performance:

- Jan 2013 – Jan 2015

Recent Accomplishments:

- Tank fabrication and TRL 5 tests are complete
- Microvalve fabrication and environmental tests are complete
- Redundant Microvalve subassembly including accumulator and volume compensator has been fabricated and tested for TRL 5
- Tank and supportive feed system components are all at JPL, ready for integration; data system complete

Next Milestones:

- Receive Busek Microvalve subassembly and test full feed system assembly to TRL 5

Application:

- Drag-free gravity wave observatories
- Remove reaction wheels - precision pointing of exo-planet observatory and next generation space telescopes
- Small spacecraft main propulsion

TRLin = ***3-4***   *TRLcurrent* = ***4***   *TRLtarget* = ***5***

Telescope for a Space GW Mission

PI: Jeff Livas/GSFC

Objectives and Key Challenges:

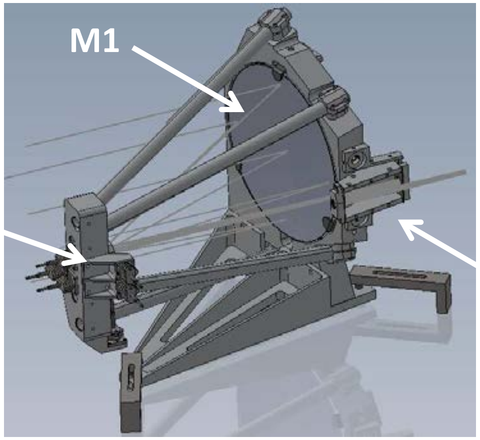
- Establish a complete telescope design meeting optical, mechanical, thermal, and manufacturability NGO requirements for US contribution to L2 mission
- Fabricate and test a prototype

Significance of Work:

Conflicting requirements:

- On-axis design more stable for thermal environment but higher scatter
- Off-axis design lower scatter but more difficult to build (hence expensive)
- Can an on-axis design meet requirements? Or
- Can an off-axis design be manufactured? **YES**

Off-axis Design Prototype in Process



Approach:

- Use SGO-Mid reference and the ESA eLISA
- "Yellow Book" to generate requirements
- L3/SSG for basic design (off-axis SiC recommended)
- Fabricate a prototype from the design
- Verify for compliance with specifications
- **Concentrate on stray light model validation**

Key Collaborators:

- Code 551: Joe Howard/Garrett West/Peter Blake/Len Seals/Ron Shiri/
- Code 543: John Crow/Justin Ward

Current Funded Period of Performance:

- Oct 2012 – Sept 2014
- Oct 2014 – Sept 2015 no cost extension

Recent Accomplishments and Next Milestones:

- Nov 2013: Telescope RFP terminated: no award
- Dec 2013: Simplified telescope model
- Apr 2014: Telescope mirror specs completed
- Jun 2014: Prototype model contract signed
- Oct 2014: Prototype CDR
- Mar 2014: Prototype Telescope delivery to GSFC
- Apr 2014: Prototype Telescope aligned
- Sep 2015: System-level scattered light model validated

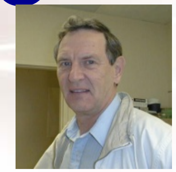
Application:

- Flagship gravitational wave missions (eLISA)
- Laser ranging; precision metrology applications
- Laser communications

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

Laser Stabilization with CO

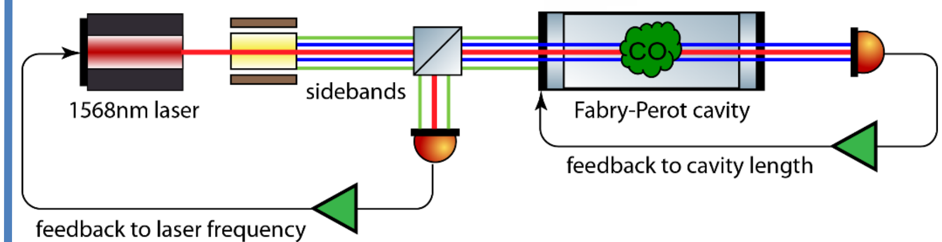
PI: John Lipa/Stanford University



Objectives and Key Challenges:

- Develop a laser operating near 1570 nm with improved noise performance and mid-term frequency stability, for missions that could use a highly coherent light source near the telecom band.
- Performance goals are to achieve substantially lower noise than Iodine-stabilized lasers, the current gold standard for transportable systems. Goal is to achieve an Allan deviation of ~ 2×10^{-15} in a one second measurement time.

Challenge: Noise performance and frequency stability of lasers on short and intermediate time scales: requires dual locking scheme shown on right.



Dual sideband laser locking optics

Significance of Work:

- A highly stable laser simultaneously locked to a cavity and a molecular transition at a Telecom wavelength.

Approach:

- Set up a bench-top model of laser system for CO based on existing system at JILA for C2HD near 1064 nm
- Perform functional tests on system
- Set up a system to allow detailed noise performance measurements
- Upgrade optics and electronics to achieve noise performance goal

Key Collaborators:

- Jan Hall, JILA
- Bob Byer, Sasha Buchman, Stanford
- Shailendhar Saraf, SN&N Electronics, CA

Current Funded Period of Performance:

- Jan 2013 – Dec 2014 (no-cost extension to 6/15)

Recent Accomplishments:

- Laser stabilization system fully functional 6/14
- First ever CO stabilized laser 9/14
- Initial noise measurement 11/14

Next Milestones:

- Noise measurements using frequency comb 1/15
- Noise measurements with reference cavity 3/15
- Documentation of final TRL 5/15

Application:

- Applications would be tests of fundamental physics, gravity wave observation, precision spectroscopy and Doppler, formation flying, trace gas detection.

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

Planar Antenna-Coupled Superconducting Detectors for CMB Polarimetry

PI: James Bock/JPL

Objectives and Key Challenges:

Advance antenna-coupled superconducting detector technologies for space requirements:

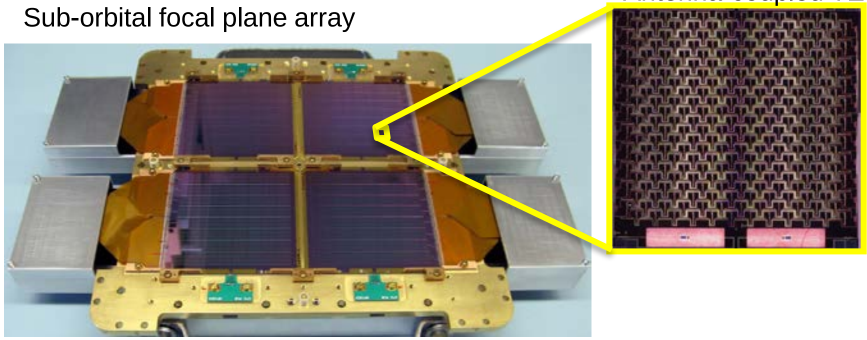
- Antenna design and performance
- Propagation losses
- Develop and test modular focal plane units
- MKIDs for CMB science
- TES stability & cosmic-ray response
- Extended-frequency antennas
- Readout noise stability

Significance of Work:

- RF propagation properties of antennas
- Detector sensitivity, stability, and minimized particle susceptibility

Sub-orbital focal plane array

Antenna-coupled TES



Approach:

- Planar antennas provide entirely lithographed fabrication with no coupling optics
- Design scales to all bands required for Inflation Probe from 30 to 300 GHz
- Detectors provide photon-limited sensitivities in space
- Antennas provide excellent polarization and beam-matching properties
- Modular focal-plane unit for large focal plane arrays

Key Collaborators:

- Koko Megerian, Hien Nguyen, Roger O'Brient, Anthony Turner, Alexis Weber (JPL)
- Jeff Filippini, Sunil Golwala, Howard Hui , Zak Staniszewski (Caltech)
- Chao-Lin Kuo (Stanford)

Current Funded Period of Performance:

- October 2013 – September 2015

Recent Accomplishments:

✓Tested sample of far-field beams of tapered antennas
✓220 GHz focal planes developed and characterized
✓Optimized magnetic shielding of 95 GHz focal plane module
✓Characterized loss and coupling at 250 GHz

Next Milestones:

- Flight of SPIDER for particle response demonstration (Jan 2015)
- Full test of far-field beams of tapered antennas (Mar 2015)
- 40 GHz antenna design (Feb 2015)
- Beam-tests of module in representative optics (April 2015, delayed)

Applications:

- NASA *Inflation Probe* mission
- Explorer & international CMB missions
- Technology commonalities with Far-IR and X-Ray missions

TRL $_{In}$ = **3-4** *TRL $_{PI-Asserted}$* = **3-5** *TRL $_{Target}$*= **4-6**

Demonstration of a TRL 5 Laser System for eLISA

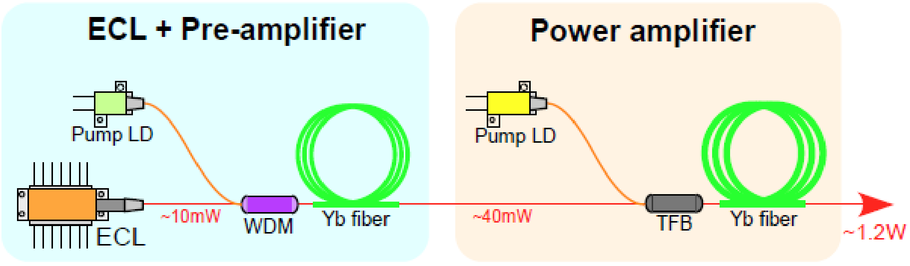
PI: Jordan Camp / GSFC

Objectives and Key Challenges:

- Develop 1.5W light source for the eLISA gravitational wave mission using a Master Oscillator Power Amplifier design with a novel diode laser oscillator (External Cavity Laser, ECL) followed by a 1.5W Yb fiber amplifier, providing a highly stable, compact, and reliable system
- Test the laser system for reliability, and for amplitude and frequency stability, achieving the required noise performance
- Demonstrate system TRL 5

Significance of Work:

- Development, with industrial partner (Redfern Integrated Optics), of space qualified, ultra low-noise oscillator
- Demonstration of low-noise power amplifier with servo controls
- Noise and reliability tests of full laser system



Master Oscillator / Power Amplifier (MOPA) configuration of eLISA laser, including ECL, preamp, and diode pumped Ytterbium (Yb) fiber amplifier

Approach:

- Noise optimization of 1064 nm External Cavity Laser (RIO)
- Reliability study of External Cavity Laser
- Implementation of amplitude and frequency servo controls on full laser system, achieving RIN=10^{-4} at 10^{-3} Hz, frequency noise = 300 Hz / $Hz^{1/2}$ at 10^{-2} Hz, and differential phase noise = 6×10^{-4} rad/$Hz^{1/2}$ at 10^{-2} Hz

Key Collaborators:

- Kenj Numata, Mike Krainak (NASA/GSFC)
- Lew Stolpner (Redfern Integrated Optics)

Current Funded Period of Performance:

- April 2014 – April 2016

Recent Accomplishments and Next Milestones:

- ✓ Developed and constructed 1.5 W laser amplifier
- ✓ Fabricated world's first butterfly package layout 1064 nm ECL
- Rebuild and test 1.5 W laser amplifier (Aug 2014)
- Preliminary laser system test with NPRO (Dec 2014)
- Noise optimization of ECL optical cavity (Dec 2014)
- Preliminary laser system test with ECL (Mar 2015)
- Noise optimization of ECL gain chip (Jun 2015)
- ECL reliability tests (Aug 2015)
- Full laser system noise testing (Jan 2016)
- Full laser system reliability testing (Mar 2016)

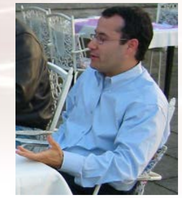
Applications:

- Laser source for eLISA Gravitational Wave mission
- Oscillator for ground-based GW LIGO project
- Oscillator for GRACE-II mission

TRL_{In} = **3** $TRL_{Current}$ = **3** TRL_{Target} = **5**

Gravitational-Wave Mission Phasemeter Technology Development

PI: William Klipstein, JPL

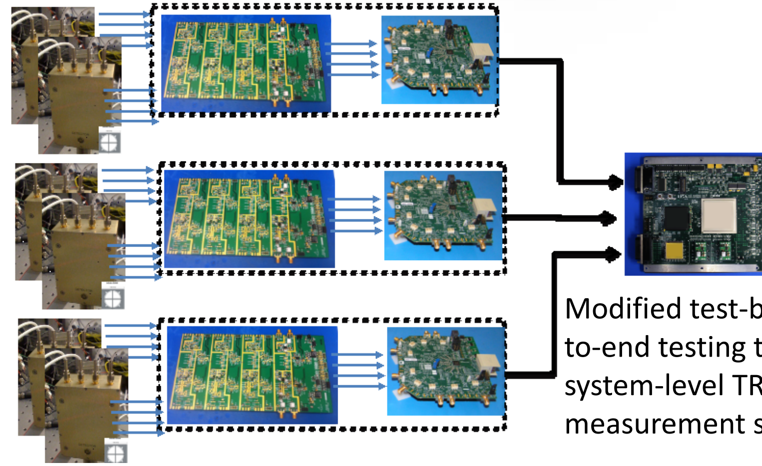


Description and Objectives:

- Advance technology readiness level (TRL) of phase-measurement electronics and demonstrate performance in upgraded interferometer-system-level test-bed providing signals representative of gravitational-wave missions, such as the *Laser Interferometer Space Antenna* (LISA)

Key Challenge/Innovation:

- High-strain sensitivity requires micro-cycle/$Hz^{1/2}$ precision on a 4-18 MHz beat-note in the presence of laser frequency noise and local clock noise
- We have demonstrated such phase readout in an interferometer test-bed and plan to mature the technology



Modified test-bed for end-to-end testing to advance system-level TRL of phase measurement system

Approach:

- Advance component technologies
  - o Advance maturity of analog signal chain
  - o Demonstrate wave-front sensing with quadrant photo-receivers
  - o Complete design trade for reducing photo-receiver size
- System-level testing
  - o Modify interferometer test-bed to include low-light signals
  - o Replace COTS components in interferometer test-bed with higher-TRL units and demonstrate performance

Key Collaborators:

- Jeff Dickson, Brent Ware, Bob Spero, Kirk McKenzie, Glenn de Vine, Andrew Sutton (JPL)

Development Period:

- April 2014 – March 2016

Accomplishments and Next Milestones:

- Design 2nd generation analog signal chain (Nov 2014)
- Build 2nd generation analog signal chain (Feb 2015)
- Demonstrate wave-front sensing (Sep 2015)
- Implement quadrant photo-receivers in existing test-bed (Dec 2015)

Applications:

- Inter-spacecraft laser interferometry
- Interferometer readout electronics with picometer precision
- Future space mission, e.g., LISA
- Capability supports other interferometry concepts (e.g., exo-planet finding)

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

Development of Fabrication Process for Critical-Angle X-ray Transmission Gratings

PI: Mark Schattenburg/MIT MKI

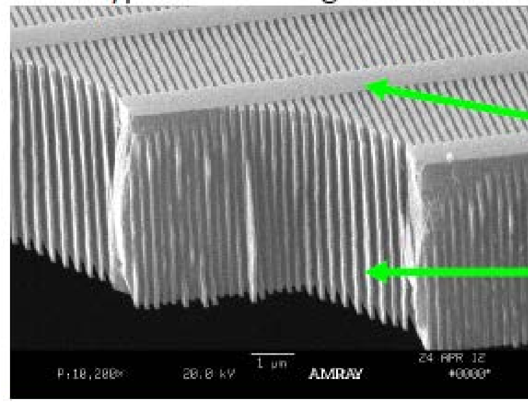
Objectives and Key Challenges:

- Develop key technology to enable a Critical-Angle X-ray Transmission Grating Spectrometer (CATGS), advancing to TRL-6 in preparation for proposed missions or Explorers over the next two decades
- Develop improved grating fabrication processes and procure advanced etching tool and other infrastructure in order to accelerate technology development

Significance of Work:

- Development of nanofabrication technology for the silicon nanomirror grating elements
- Development of microfabrication processes for the integrated grating support mesh

Prototype CAT Grating



Approach:

- Integrated wafer front/back-side fabrication process using silicon-on-insulator (SOI) wafers
- Wafer front side: CAT grating structure + Level 1 support
- Wafer back side: Level 2 support hex-mesh structure
- CAT grating fabricated by deep reactive ion-etching (DRIE) followed by KOH polishing
- Bonded to expansion-matched metal support frame (Level 3 support)
- X-ray testing of prototypes at synchrotrons and MSFC facility

Key Collaborators:

- William Zhang (GSFC)
- Steve O'Dell (MSFC)

Current Funded Period of Performance:

- FY12-FY14

Recent Accomplishments and Next Milestones:

- Developed improved DRIE process with significantly reduced line bowing. Developed improved backside etch process.
- Demonstrated KOH polish to full 4.0 µm depth following DRIE.
- Demonstrated fully-integrated 31x31 mm^2 grating with KOH polish.
- Developed novel process to produce stress-controlled SOI wafers.
- Acquired and installed new DRIE tool (SPTS Pegasus) in SNL.
- Transferred process to new tool and demonstrated excellent etch profile control.
- Fabricated CAT gratings with record soft x-ray diffraction efficiency.

Application:

- Flagship, Probe and Explorer class x-ray astronomy missions requiring high resolution spectroscopy
- Laboratory x-ray analysis (materials science, energy research)

TRLin = ***3*** *TRLcurrent* = ***3*** *TRLtarget* = ***6***

Adjustable X-Ray Optics with Sub-Arcsecond Imaging

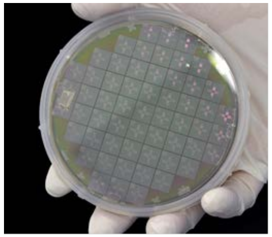
PI: Paul Reid/SAO

Objectives and Key Challenges:

- Develop adjustable light weight x-ray optics with sub arcsecond performance
- Create the enabling optics technology for a large aperture high resolution x-ray mission (SMART-X) for selection at the next Decadal Survey

Significance of Work:

- Sub-arcsecond optics fabricated with traditional methods are too heavy; light, thin replicated optics performance is limited to ~7”
- By coating thin glass optics with piezoelectric material, whose shape can be altered by applying a voltage, we can correct unwanted figure distortions improving performance to <1”



Adjustable mirror with strain gauges on every cell

Mirror pair during alignment

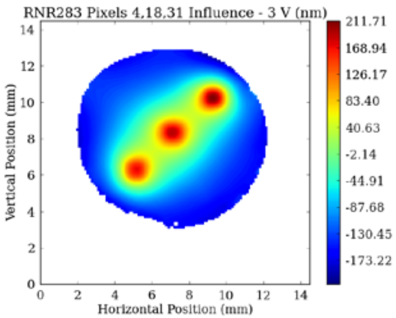


Figure change from three non-adjacent piezo cells energized simultaneously, measured with Shack-Hartmann wavefront sensor

Approach:

- Deposit piezoelectric material (PZT) on conical thermally formed glass
- Mount and align a piezo coated mirror pair
- Correct unwanted figure distortions by adjusting the voltage applied to the piezo material
- Prove out performance using x-ray testing

Key Collaborators:

- Susan Trolier Mckinstry (PSU)
- Brian Ramsey and Stephen O’Dell (MSFC)

Current Funded Period of Performance:

- Feb 2013 – Jan 2016

Recent Accomplishments:

- Demonstrated predicable, repeatable deformations on cylindrical optics that matched values predicted by models
- Completed mounting and aligning of mirror pair using first generation mount; starting mount design improvement phase
- Deposited strain gauges on piezo cells
- Calculated PZT life of > 1000 years from accelerated lifetime test results

Next Milestones:

- Mount / align improved conical optics in TRL-4 mount

Application:

- Large aperture and high resolution x-ray mission for the 2020s (Square Meter Arcsecond Resolution X-ray Telescope, SMART-X)

*TRLin = **2***   *TRLcurrent est. by PI = **3***   *TRLtarget = **4***

Reflection Grating Modules: Alignment and Testing

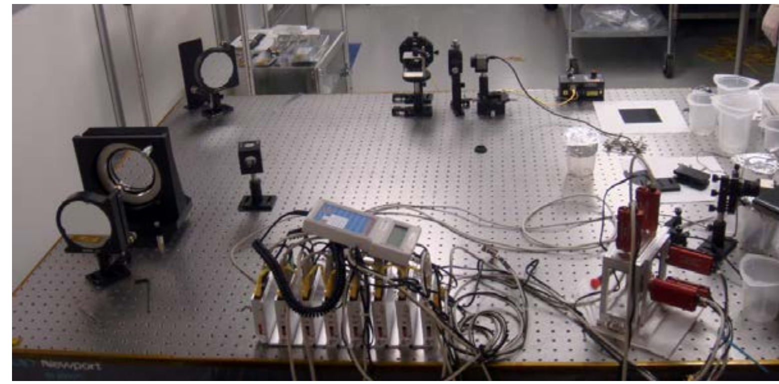
PI: Randall McEntaffer/University of Iowa

Objectives and Key Challenges:

- To increase the TRL of off-plane gratings
- Align multiple gratings into flight-like modules
- Performance test aligned gratings for spectral resolving power
- Environmental test modules with performance verification

Significance of Work:

- Enables future spectrometers to accomplish key soft X-ray science goals that require high sensitivity combined with high spectral resolving power



Upper left: Metrology system for grating alignment,
Lower right: Grating module with pico actuators

Approach:

- Leverage from previous SAT and supporting programs to supply gratings and preliminary designs
- Align gratings into module using proven methods
- Use Stray Light Facility at MSFC for performance and environmental testing

Key Collaborators:

- Jessica Gaskin, MSFC
- Will Zhang, GSFC

Current Funded Period of Performance:

- 01/2015 – 12/2016

Recent Accomplishments:

- ✓ Initial testing of prototype gratings has been accomplished
- ✓ Alignment tolerances are known
- ✓ Initial modules have been fabricated and tested

Next Milestones:

- Test active and passive module mounts (Year 1)
- Increase fidelity of module mount and alignment methodology (Year 1 – Year 2)
- Test flight-like aligned module (Year 2)

Application:

- Suborbital rocket missions - OGRE
- Small Explorers - Arcus

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

Next Generation X-ray Optics: High-Resolution, Lightweight, and Low-Cost

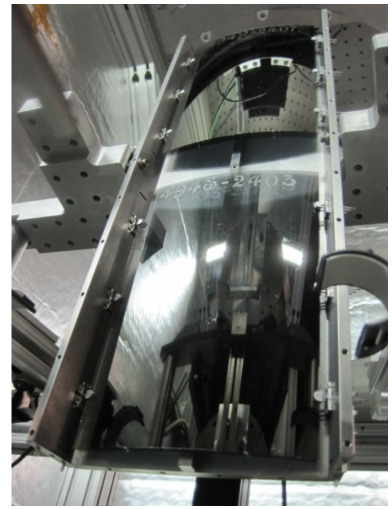
PI: William W. Zhang/GSFC

Objectives and Key Challenges:

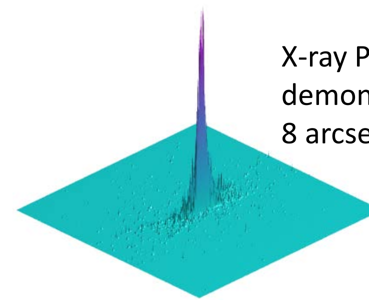
- Develop a lightweight X-ray mirror technology achieving better than 5” HPD angular resolution, advancing it to TRL 5, and readying it to enable missions planned for both 2010’s and 2020’s
- Mature and perfect this technology to minimize cost and schedule
- Prepare ways to achieve significantly better than 5” resolution while keeping mass and cost at similar levels

Significance of Work:

- Fabrication and metrology of mirror segments
- Alignment and bonding of mirror segments



A Technology Development Module (TDM) containing three pairs of parabolic-hyperbolic mirror segments that has passed both performance and environmental test



X-ray PSF demonstrating 8 arcsec HPD

Approach:

- Make mirror substrates by slumping glass or polishing silicon
- Maximize X-ray reflectance using magnetron sputter or atomic layer deposition
- Measure performance using interferometer, null lens, and interferometric microscope
- Align mirror segments using Hartmann tests
- Develop precision epoxy bonding techniques

Key Collaborators:

- Michael Biskach, Kai-Wing Chan, Ryan McClelland, Timo Saha (NASA/GSFC)
- Stephen O’Dell (NASA/MSFC)

Current Funded Period of Performance:

- October 2014 – September 2016

Recent Accomplishments:

✓ Repeatedly co-aligned and bonded multiple mirror pairs, achieving 8” HPD X-ray Point Spread Function (PSF, see lego plot above)

Next Milestones:

- Transition from using glass substrates to using single crystal silicon substrates by December 2015
- Build and test technology development modules with silicon substrates and achieve 5” HPD by December 2016

Applications:

- Backup technology for ESA’s Athena mission
- Flagship and probe-class X-ray missions
- Explorer-type X-ray missions
- Sounding rocket and balloon experiments
- Medical research and diagnosis

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

Fast Event Recognition for the ATHENA Wide Field Imager

PI: David Burrows / PSU

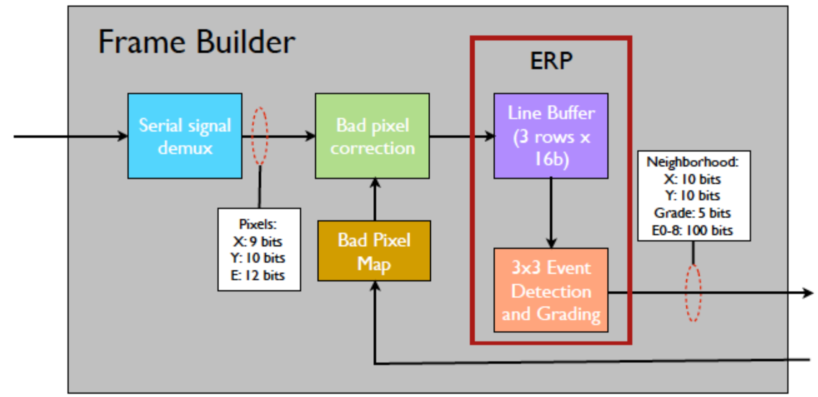
PENNSTATE

Objectives and Key Challenges:

- High-speed event recognition and data compression

Significance of Work:

- Required for future proposed X-ray imagers, including *Athena* WFI (ESA L2), *JANUS* XCAT (EX), *XTiDE* XCAT (SMEX), *Arcus* (ISS), *X-ray Surveyor* (Astrophysics Roadmap)



Approach:

- FPGA coding/simulation/testing
- Testing with fixed patterns up to 1GB/s
- Testing with real X-ray data up to 1GB/s

Key Collaborators:

- Dr. Karl Reichard, Eli Hughes (PSU/ARL)
- Dr. Zach Prieskorn, Dr. Tyler Anderson (PSU/ECOS)
- Dr. Mark Bautz (MIT), Dr. Steve Murray (SAO)

Current Funded Period of Performance:

- 1/2015 – 12/2016

Recent Accomplishments:

✓ Initiated internal funding codes, ordered development kit

Next Milestones:

- Design Review, July 2015

Applications:

- Including *Athena* WFI (ESA L2), *JANUS* XCAT (EX), *XTiDE* XCAT (SMEX), *Arcus* (ISS), *X-ray Surveyor* (Astrophysics Roadmap)…

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