Physics of the Cosmos (PCOS) Strategic Technology Development Portfolio

December 2015

Current PCOS Technology Development Portfolio

Funding Source	Technology Development Title	Principal Investigator	Org	Start Year	TRL	Science Area	Tech Area
SAT2010	Directly-Deposited Blocking Filters for Imaging X-ray Detectors: Technology Development for the International X-ray Observatory	Mark Bautz	MIT	FY2012, 4 years	5	X-ray	Detectors
SAT2011	Advanced Laser Frequency Stabilization	John Lipa	Stanford	FY2013, 3 years	3	GW	Lasers
SAT2011	Telescope for a Space-based Gravitational Wave Mission	Jeffrey Livas	GSFC	FY2013, 3 years	3	GW	Telescope
SAT2011	Demonstrating Enabling Technologies for the High-Resolution Imaging Spectrometer of the Next NASA X-ray Astronomy Mission	Caroline Kilbourne	GSFC	FY2013, 3 years	4	X-ray	Detectors
SAT2012	Phase Measurement System Development for Interferometric Gravitational Wave Detectors	William Klipstein	JPL	FY2014, 3 years	4	GW	Phasemeter
SAT2012	Demonstration of a TRL 5 Laser System for eLISA	Jordan Camp	GSFC	FY2014, 2 years	3	GW	Lasers
SAT2013	Technology Development for an AC-Multiplexed Calorimeter for ATHENA	Joel Ullom	NIST	FY2015, 2 years	3	X-ray	Detectors
SAT2013	Fast Event Recognition for the ATHENA Wide Field Imager	David Burrows	PSU	FY2015, 2 years	3	X-ray	Detectors
SAT2013 & SAT2010	Reflection Grating Modules: Alignment and Testing	Randy McEntaffer	U. of Iowa	FY2015, 2 years	4	X-ray	Optics
SAT2013 APRA2011	Development of 0.5 Arc-second Adjustable Grazing Incidence X-ray Mirrors for the SMART-X Mission Concept	Paul Reid	SAO	FY2015, 3 years	3	X-ray	Optics
SAT2013 & SAT2011	Affordable and Lightweight High-Resolution Astronomical X-Ray Optics	William Zhang	GSFC	FY2015, 2 years	5	X-ray	Optics
SAT2013 & SAT2010	Advanced Packaging for Critical Angle X-ray Transmission Gratings	Mark Schattenburg	MIT	FY2015, 2 years	3	X-ray	Optics
SAT2014	High Efficiency Feedhorn-Coupled TES-based Detectors for CMB Polarization Measurements	Edward Wollack	GSFC	FY2016, 2 years	3	CMB	Detectors
SAT2014 & SAT2011	Telescope Dimensional Stability Study for a Space-based Gravitational Wave Mission	Jeffrey Livas	GSFC	FY2016, 2 years	3	GW	Telescope
SAT2014 & SAT2012	Superconducting Antenna-Coupled Detectors and Readouts for Space-Borne CMB Polarimetry	James Bock	JPL	FY2016, 2 years	3 - 5	CMB	Detectors

Deposited Blocking Filters for X-ray Detectors

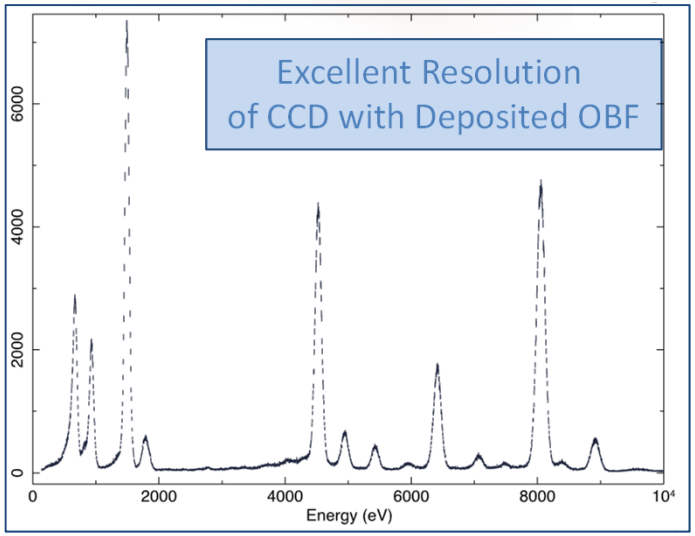
PI: Mark Bautz/MIT MKI

Objectives and Key Challenges:

- Silicon Imaging X-ray detectors require thin filters (<300 nm) to block noise/background from UV and optical light
- State-of-the-art, free-standing filters use fragile, thin substrates
- Objective: deposit blocking filter directly on CCD X-ray detector, eliminating substrate
- Challenges:
  - Deposit filter directly without compromising CCD performance
  - Deposit sufficiently thin, uniform filters

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



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, 2016

Accomplishments and Next Milestones:

- Reduced pinhole fraction to < 1% (OD<7) for 220nm OBF
- Tested devices 70nm & 100nm thick Al OBF. Optical blocking as expected.
- With REXIS, developed & qualified underside coating as effective countermeasure for near-IR leakagethrough package.
- Long-term stability test in progress; no degradation in 8 months
- Supported env. tests of REXIS flight CCDs/OBFs, achieved TRL-6, ***surpassing project goals.***
- Complete stability test and final publication by end date.

Application:

Every X-ray imaging or grating spectroscopy mission

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

TRLin = 5 TRLcurrent = 6 TRLtarget = 6

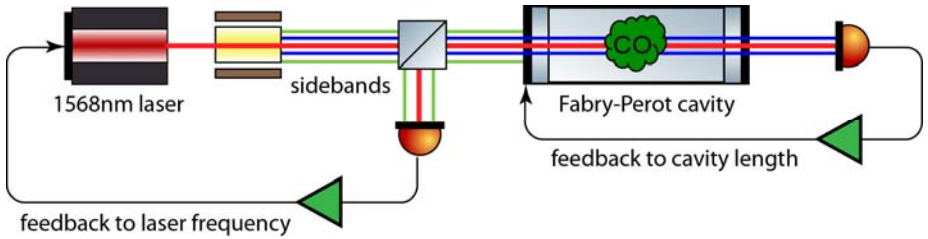
Laser Stabilization with CO

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 ~ $2x10^{-15}$ 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

Funded Period of Performance:

- Jan 2013 – Jan 2015

Accomplishments:

- First demonstration of CO stabilized laser in the telecom wavelength band (~1550 nm) (~ 06/14)
- Noise measurements to $2x10^{-14}$ stability @ 1000 sec (10/15)
- Performance upgrades with frequency comb reference (11/15)
- Publication of results (submitted) (11/15)

Next Milestones (separately funded):

- Testing with lower noise resonant photodetector (~03/16)
- Documentation of final TRL (~ 11/16)

Application:

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

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

Telescope for a Space GW Mission

PI: Jeff Livas/GSFC

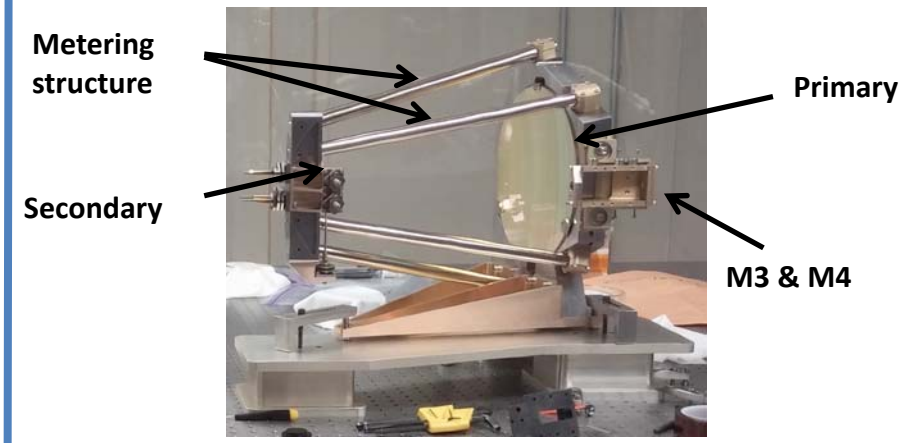
Objectives and Key Challenges:

- Establish a complete telescope design meeting optical, mechanical, thermal, and manufacturability requirements for the US contribution to the eLISA L3 mission
- Fabricate and test a prototype
- Validate stray light model

Significance of Work:

- First demonstration of a validated scattered light model combined with a previous demonstration of dimensional stability provides a firm basis for a realistic engineering model design for a flight-qualifiable off-axis telescope with low scattered light and high dimensional stability.

Off-axis Prototype as Delivered



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

Currently Funded Period of Performance:

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

Recent Accomplishments:

- Jun 2014: Prototype model contract signed
- Oct 2014: Prototype CDR
- Jun 2015: Prototype Telescope delivery to GSFC

Next Milestones:

- Jul 2015: Prototype Telescope aligned at GSFC
- Aug 2016: System-level scattered light model validated

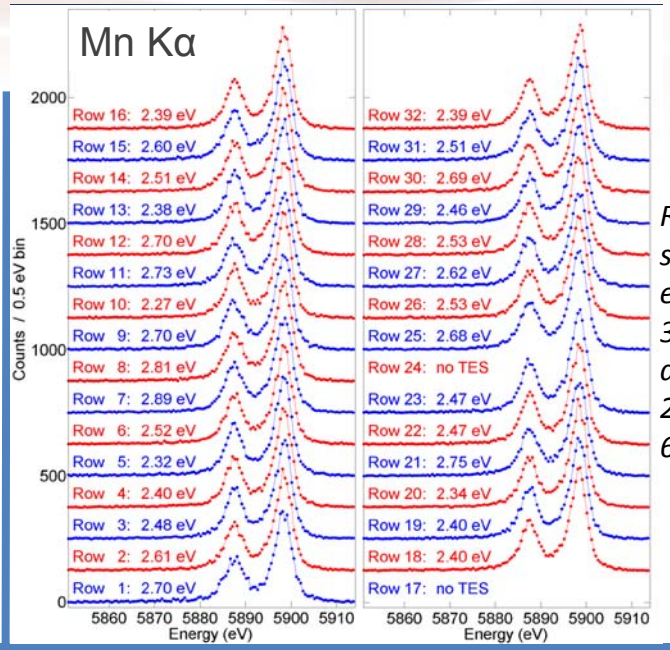
Application:

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

$TRL_{In} = 2$ $TRL_{PI\text{-}Asserted} = 3$ $TRL_{Target} = 3+$

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

PI: Caroline Kilbourne/GSFC (662)



Reaching multiplexer speed and noise goals enabled breakthrough 32-row read-out demonstration with 2.55 eV resolution at 6 keV

Objectives and Key Challenges:

- Develop large-format arrays of X-ray microcalorimeters and their readout that meet the challenging requirements of high-resolution X-ray imaging spectrometers for astrophysics
- Advance the key components of an X-ray microcalorimeter imaging spectrometer from TRL 4 to 5, and advance a number of important related technologies to at least TRL 4

Significance of Work:

- This solid demonstration of core technologies coupled with a demonstration of targeted enhancements will enable a number of mission concepts to be confidently considered.
- This development has enabled NASA participation in the ESA Athena mission.

Approach:

- Optimize SQUID time-division multiplexer (TDM) components and back-end electronics for low crosstalk, acceptable power dissipation, and bandwidth sufficient for frame times of 160 ns.
- Integrate state-of-the-art 32x32 TES arrays (Mo/Au TES with Au/Bi absorbers) with optimized multiplexed readout.
- Advance code-division multiplexer (CDM) readout
- Investigate component technologies for focal-plane assembly

Key Collaborators:

- (GSFC) 662: J. Adams, S. Bandler, R. Kelley, R.S. Porter, S. Smith, 553: J. Chervenak
- (NIST) J. Ullom, W. B. Doriese, C. Reintsema
- (Stanford) K. Irwin

Current Funded Period of Performance:

- October 2012 – September 2015

Recent Accomplishments:

✓ Many improvements in the design of TDM and CDM components and systems, with all noise and bandwidth goals now met.

✓ Multiplexed 32 rows in a single column with an average resolution at 6 keV of 2.55 ± 0.1 eV.

Next Milestones:

- Demonstrate multiplexed (3 columns x 16 rows) readout of 96 different flight-like pixels with 0.25 mm pitch in a 32 x 32 array with > 95% of pixels achieving better than 3 eV resolution at 6 keV

Application:

- Contribution to the X-ray Integral Field Unit instrument on the ESA Athena mission.
- Other potential missions needing high-resolution imaging x-ray spectroscopy.

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

Gravitational-Wave-Mission Phasemeter Technology Development

PI: Bill Klipstein/JPL

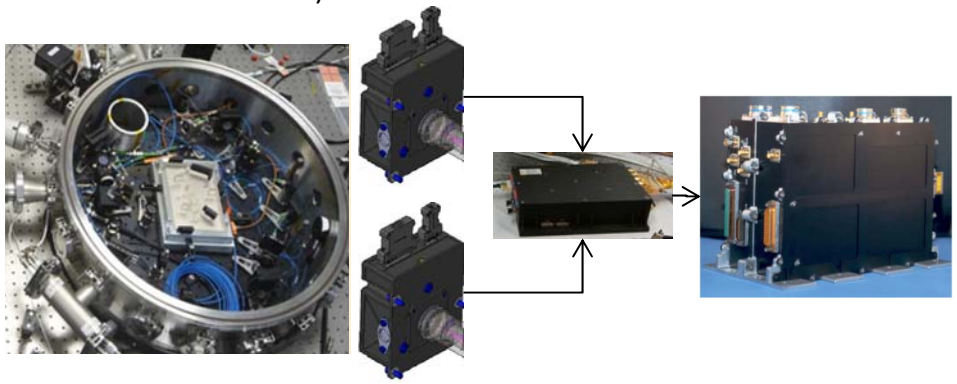
Objectives and Key Challenges:

- Advance our phase-measurement system from TRL 4 to 5 through significant system-level hardware fidelity increase and greater fidelity of signal test environment by adding low light levels
- Mature the TRL of phase readout with high strain sensitivity through micro-cycle/√Hz precision on a 4-16 MHz beat-note in the presence of laser frequency noise and local clock noise, already demonstrated in a lab testbed

Significance of Work:

- High-performance phase readout is an enabling technology for multi-spacecraft laser-interferometer-based missions such as LISA-like gravitational-wave missions

EM Hardware (QPD Photoreceivers, Pre-Amp, and Phasemeter) infused into the LISA Testbed



Approach:

- Advance component technologies
  - Infuse compatible EM hardware from GRACE Follow-On Laser-Ranging Interferometer (LRI)
  - Demonstrate wavefront sensing with quadrant photoreceivers
- System-level testing
  - Modify interferometer testbed to include low-light signals
  - Replace COTS components in interferometer testbed with LRI EM hardware and demonstrate performance

Key Collaborators:

- Jeff Dickson, Brent Ware, Bob Spero, Kirk McKenzie, Andrew Sutton, and Chris Woodruff (JPL)

Current Funded Period of Performance:

Apr 2014 – Sep 2016

Recent Accomplishment:

✓ Demonstrated phase readout with micro-cycle/√Hz precision in the presence of laser frequency noise and local clock noise in an interferometer testbed

Next Milestones:

- Incorporate Quadrant Photoreceivers into testbed *FY16 Q2*
- Demonstrate wave-front sensing *FY16 Q2*
- Migrate additional photoreceiver algorithms from LabView phasemeter to EM *FY16 Q4*
- Demonstrate tracking of low visibility signals with EM Phasemeter *FY16 Q3*
- Incorporate EM photoreceivers and signal chain *FY16 Q4*
- Demonstrate testbed performance at TLR 5 or better *FY17 Q1*

Applications:

- Inter-spacecraft laser interferometry and pm-precision interferometer readout electronics for future missions, *e.g.*, LISA
- Other interferometry concepts (*e.g.*, planet searches)

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

Demonstration of a TRL 5 Laser System for LISA

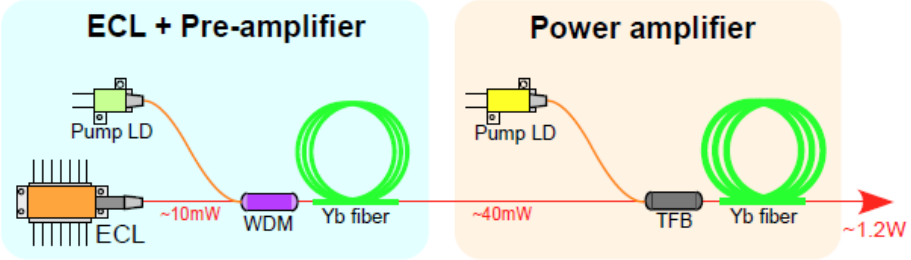
PI: Jordan Camp/GSFC

Objectives and Key Challenges:

- Develop 2.5W light source for the LISA gravitational wave mission using a Master Oscillator Power Amplifier design with a novel diode laser oscillator (External Cavity Laser, ECL) followed by a 2.5W 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 LISA 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 = $6x10^{-4}$ 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

Accomplishments and Next Milestones:

- ✓ Fabricated world's first butterfly package layout 1064 nm ECL
- ✓ Procurement of long lead items: fiber splicers and coaters
- ✓ Developed and constructed 2.5 W laser amplifier
- ✓ Preliminary laser system test with External Cavity Laser (ECL)
- Noise optimization of ECL optical cavity — Mar 2016
- ECL reliability tests — Mar 2016
- Amplifier reliability tests — June 2016
- Full laser system reliability testing — Oct 2016

Applications:

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

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

Technology Development for an AC-Multiplexed Calorimeter for ATHENA

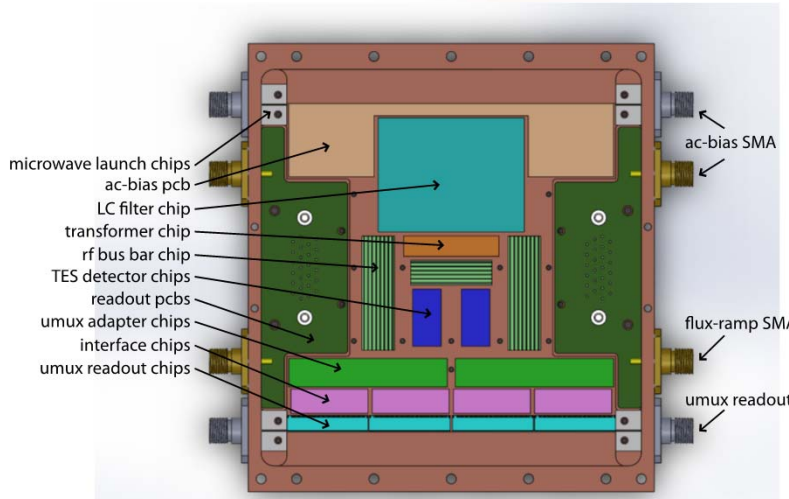
PI: Joel Ullom/NIST

Objectives and Key Challenges:

- Increase TRL of AC-biased Transition-Edge Sensor (TES) X-ray microcalorimeters from 3 to 4
- To achieve this, we seek to demonstrate that AC-biased TESs can meet the anticipated performance requirements of ESA's ATHENA mission, and in particular that AC-biased TESs can routinely achieve energy resolutions of 2.5 eV or better at 6 keV
- The key challenge is that, so far, TESs under AC-bias do not have as good energy resolution as under DC-bias

Significance of Work:

- AC-biased TESs and Frequency Division Multiplexing (FDM) are the baseline readout architecture for ATHENA; the performance of this approach strongly impacts mission design and success



Sample box design for readout of AC-biased TESs using open-loop microwave SQUIDs

Approach:

- Study the behavior of single GSFC TESs under AC-bias
- In one experiment, maximize the use of readout components from the European ATHENA team
- In a second experiment, separate the effects of the readout system from the TES by using a novel, open-loop readout architecture based on microwave SQUID amplifiers
- Study interactions among small numbers of AC-biased TES sensors

Key Collaborators:

- Caroline Kilbourne, Simon Bandler, and Richard Kelley (GSFC)
- Kent Irwin (Stanford University)

Current Funded Period of Performance:

FY 2015 – FY 2016

Recent Accomplishments:

- ✓ Good coordination with European ATHENA team and exchange of personnel and components
- ✓ Improved single pixel performance under AC-bias and 2-pixel multiplexing
- ✓ End-to-end demonstration of microwave readout and progress towards full bandwidth measurement

Next Milestones:

- Refabricate microwave SQUID amplifier (Q2 FY16)
- First operation of AC-biased TES (Q2 FY16)

Applications:

- ATHENA and future X-ray missions based on TES microcalorimeters

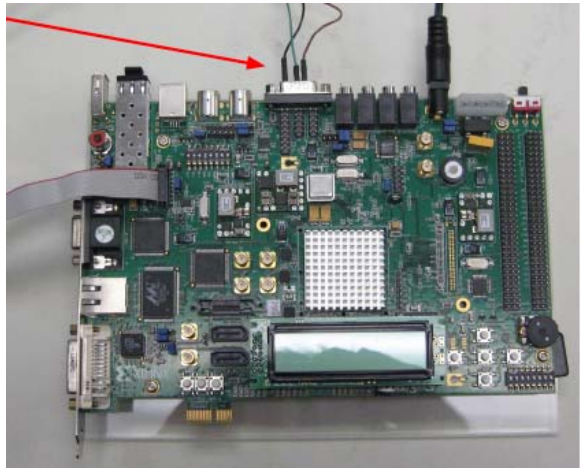
$TRL_{In} = 3$ $TRL_{Current} = 3$ $TRL_{Target} = 4$

Fast Event Readout

PI: David Burrows/PSU

Objectives and Key Challenges:

- High-speed event recognition and data compression



Significance of Work:

- Required for several 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. Ralph Kraft (SAO)

Current Funded Period of Performance:

- 1/2015 – 12/2016

Recent Accomplishments: (Year,Task listed)

✓ Completed development/testing of line processor (Y1T4, Y2T2)
✓ Simulated performance (Task 5)
✓ Completed Design Review (Task 6, 2 November 2015)

Next Milestones:

- Complete image loader
- Test design up to 100 MHz pixel rate (Y1T8)
- Design and build prototype board (Y2T3)

Application:

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

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

Reflection Grating Modules: Alignment and Testing

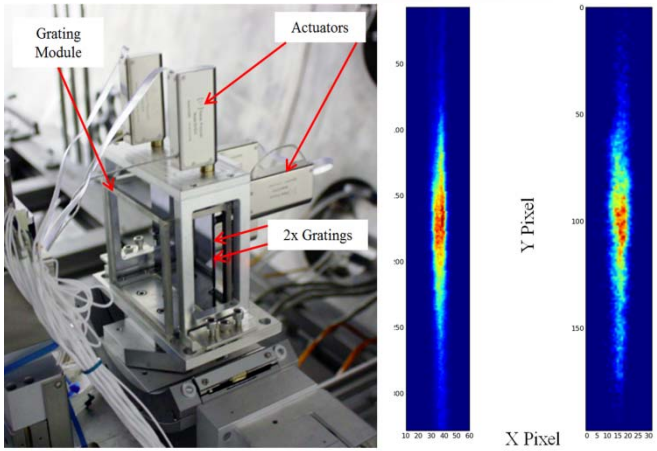
PI: Randall L McEntaffer/University of Iowa

Objectives and Key Challenges:

- Implement an alignment methodology specific to off-plane reflection gratings
- Populate a module with aligned gratings capable of achieving spectral resolutions > 3000 (λ/δλ) with high throughput over the 0.2 – 2.0 keV band
- Advance the OP-XGS technology to TRL 5

Significance of Work:

- Enables high throughput, high spectral resolving power below 2 keV where the majority of X-ray spectral features reside.
- This will be the first time that multiple off-plane gratings have been aligned at this tolerance level with associated performance testing.



Left: Aligned gratings at PANTER. Right: SPO focus (left) vs. OP-XGS focus (right)

Approach:

- Quantify alignment tolerances
- Formulate alignment methodology
- Implement alignment methodology
- Performance and environmental test an aligned module
- Evaluate process and repeat in Year 2

Key Collaborators:

- Will Zhang – NASA/GSFC
- Jessica Gaskin – NASA/MSFC

Current Funded Period of Performance:

- Jan 1, 2015 – Dec 31, 2016

Recent Accomplishments:

- ✓ Quantified alignment tolerances for suborbital and Explorer spacecraft
- ✓ Alignment methodology and grating module have completed design phase and are entering implementation
- ✓ Aligned and tested two gratings with SPO telescope at PANTER

Next Milestones:

- Implement new alignment methodology (Q4 2015 – Q1 2016)
- Performance/environmental test aligned gratings at MSFC (Q2 2016)

Application:

- Large X-ray observatories
- Explorer class missions
- Suborbital rocket investigations

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

Development of 0.5-Arcsecond Adjustable Grazing-Incidence X-ray Mirrors for the SMART-X Mission Concept

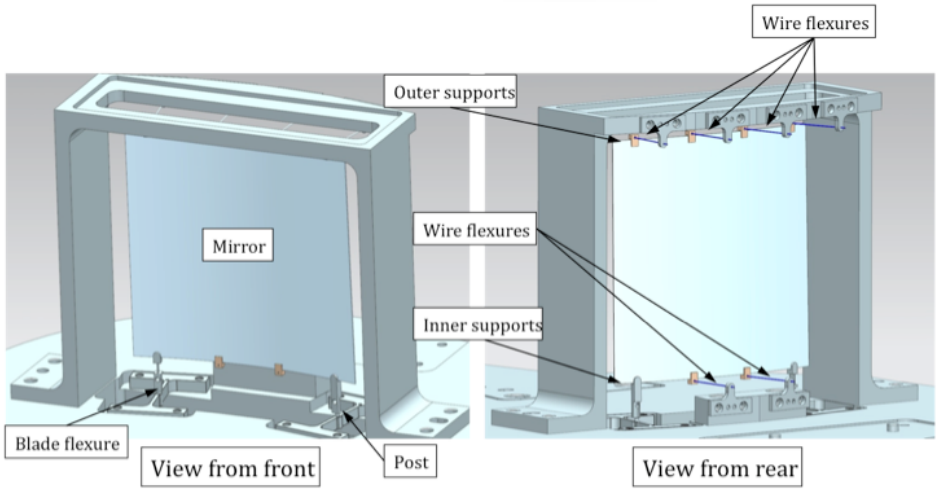
PI: Paul Reid/Smithsonian Astrophysical Observatory

Objectives and Key Challenges:

- Develop an alignment and mounting scheme consistent with a large-area (> 2m^2), high-resolution (< 0.5”) X-ray telescope that accommodates many (~100) close-packed mirror segments - align to 0.25” (= Chandra alignment) with mounting distortions < 1 µm P/V (correctable with adjusters)
- Approach must allow calibration of mirror surface figure as each segment is mounted so that figure can be corrected before aligning the next segment
- Incorporate developments in high-connection-density flexible cabling and row-column addressing to minimize and simplify electrical connections for mirror adjuster command and control

Significance of Work:

- Enables adjustable optics to correct mounting-induced distortion and on-orbit thermal changes with LCD-display electrical simplicity



Single-shell mounting concept that will be modified for multiple shells

Approach:

- Investigate anisotropic conductive films for high connection density (up to 100 contacts/mm)
- Develop ZnO thin-film transistor over-layer with insulating top layer for row-column addressing and ease of electrical contact routing
- Through structural and thermal analysis and design, incorporate and extend alignment and mounting approach being developed for APRA TRL-4 X-ray test.

Key Collaborators:

- Susan Trolier-McKinstry and Margeaux Wallace (PSU)
- Brian Ramsey and Steve O’Dell (MSFC)

Current Funded Period of Performance:

Proposed Jan 2015 – Dec 2016
Funding available Apr 2015 so plan Apr 2015 – Mar 2017

Recent Accomplishment:

✓ Completed initial thermal sensitivity analysis of thin piezoelectric film adjustable mirror in mounting concept

Next Milestones:

- Ray-tracing analysis of thermal modeling – 9/15
- Generation of thermal requirements for mirror ass’y – 10/15
- Structural Analysis and design for multi-shell ass’y – 2/16

Application:

- X-ray Surveyor (formerly SMART-X) mission concept

$TRL_{In} = 3$ $TRL_{Current} = 3$ $TRL_{Target} = 4+$

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

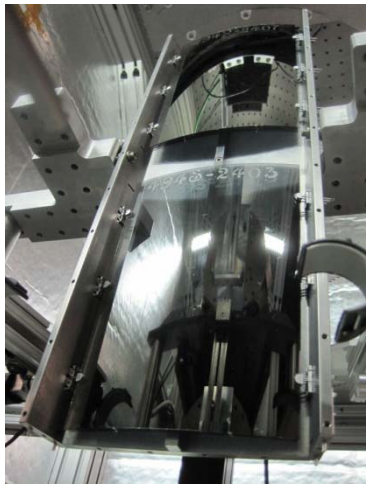
PI: William W. Zhang/GSFC

Objectives and Key Challenges:

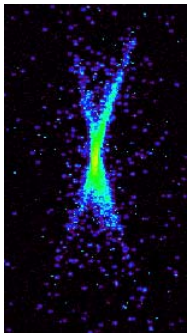
- Develop lightweight X-ray mirror technology achieving better than 10-arcsec HPD angular resolution while minimizing cost and schedule; advance to TRL 5 to enable missions planned for 2010s and 2020s
- Prepare ways to achieve significantly better than 10-arcsec resolution while keeping the mass and cost at similar levels
- Fabrication and metrology of mirror segments
- Coating mirror segments with 20 nm of iridium w/o distortion
- Alignment and bonding of mirror segments

Significance of Work:

- Enables major X-ray observatories such as ESA's ATHENA and NASA's Astrophysics Roadmap's X-ray Surveyor



Technology Development Module (TDM) containing three pairs of parabolic-hyperbolic mirror segments



X-ray image with 8-arcsec HPD

Approach:

- Precision glass slumping and polishing silicon to make mirror substrates
- Use magnetron sputter or atomic layer deposition to maximize X-ray reflectance
- Use interferometer, null lens, and interferometric microscope to conduct measurements
- Use Hartmann tests to align mirror segments
- Develop precision epoxy-bonding techniques

Key Collaborators:

- Michael Biskach, Kai-Wing Chan, Ryan McClelland, and Timo Saha (GSFC)
- Stephen O'Dell (MSFC)

Current Funded Period of Performance:

Oct 2014 – Sep 2016

Recent Accomplishments:

- ✓ Slumped mirror substrates achieving better than 10-arcsec HPD
- ✓ Coated mirror substrates with 15 nm of iridium without distortion
- ✓ Repeatedly co-aligned and bonded multiple mirror pairs, achieving 8-arcsec HPD X-ray images

Next Milestones:

- Refine mirror bonding process to fully realize mirror segment potential of 6.5-arcsec HPD
- Reduce gravity distortion by building a vertical X-ray beam to test mirror modules

Applications:

- Flagship and probe class X-ray missions
- Explorer type X-ray missions
- Medical research and diagnosis

$TRL_{In} = 3$ $TRL_{PI\text{-}Asserted} = 5$ $TRL_{Target} = 6$

Advanced Packaging for Critical-Angle X-ray Transmission Gratings

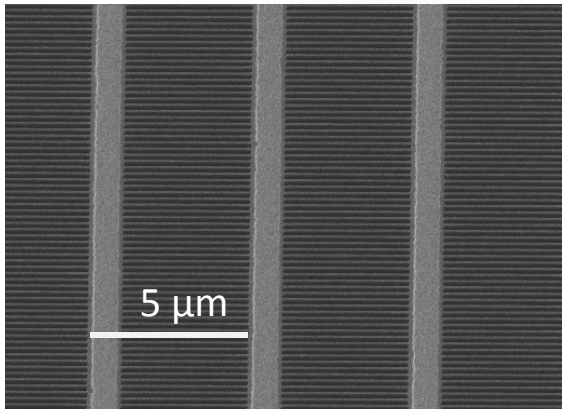
PI: Mark Schattenburg/MIT MKI

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 mid- and large-size missions over the next decade
- Develop improved grating fabrication processes
- Develop frame mounting, alignment, and assembly techniques for CAT grating arrays

Significance of Work:

- Improved diffraction efficiency and resolving power for CATGS
- Ability to manufacture large-area, light-weight grating arrays



Scanning Electron Micrograph (SEM) of a free-standing CAT grating after DRIE and KOH polish.

Approach:

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

Key Collaborators:

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

Current Funded Period of Performance:

- FY15-FY16

Recent Accomplishments:

- Optimized combined dry- and wet-etch processes to obtain smooth grating bar sidewalls and narrow L1 supports and produced free-standing large-area gratings with hierarchy of low-blockage supports
- Achieved record absolute x-ray diffraction efficiency (> 30%)

Next Milestones:

- Demonstrate CAT grating resolving power in an x-ray imaging system to achieve TRL 4 (Jan/Feb 2016)
- Demonstrate aligned gratings with prototype frame assembly to achieve TRL 5 (October 2016)

Application:

- Flagship x-ray missions
- Explorer x-ray missions
- Laboratory x-ray analysis (materials science, energy research)

TRLin = 3 ***TRLcurrent est. by PI = 3*** ***TRLtarget = 6***

High Efficiency Feedhorn-Coupled TES-based Detectors for CMB Polarization

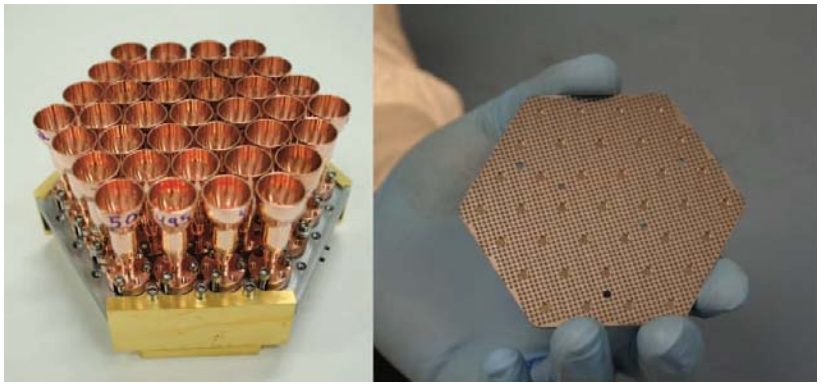
PI: Edward J. Wollack/NASA GSFC

Objectives and Key Challenges:

- Development of focal planes for characterization of CMB polarization with the following detector properties:
  - Background limited millimeter-wave polarimetric sensor with high coupling efficiency and systematic error control.
  - Inherently broadband design, scalable to large format arrays over multiple frequencies of astrophysical interest.

Significance of Work:

- Sub-orbital and space-borne operation of detectors, including
  - Improved rejection of stray light by detector architecture
  - Improved broadband performance and coupling efficiency
  - Mitigation of space environmental concerns (surface/deep dielectric charging & cosmic rays)



(left) Hyridized 90GHz Focal Plane; (right) Detector Wafer

Approach:

- The effort is focused around 3 fabrication runs to integrate the new technologies into the detector architectures. Specifically, improved:
  - Stray light mitigation and package thermalization
  - Implementation of air bridge crossovers and ground-plane contacts for large bandwidth/low loss signal routing at higher frequencies

Key Collaborators:

- K. Denis (GSFC), K. Rostem (GSFC/JHU), K. U-Yen (GSFC), S.H. Moseley (GSFC)
- D. Chuss (Villanova)
- T. Marriage, C. Bennett (JHU)

Current Funded Period of Performance:

- Start: 1/1/2016, End: 12/31/17

Recent Accomplishments:

✓ Funding received, test, and efforts initiated…

Next Milestones:

- Air bridge design and fabrication development (April 2016)
- W-band package design validation (July 2016)
- Test equipment procurement of commissioning (August 2016)
- Device bilayer development (April 2016)
- Device run #1 (August 2016)

Application:

- Cosmic Microwave Background Polarimetry, CMBpol, suborbital

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

Telescope Dimensional Stability Study for a Space-based GW Mission

PI: Jeff Livas/GSFC

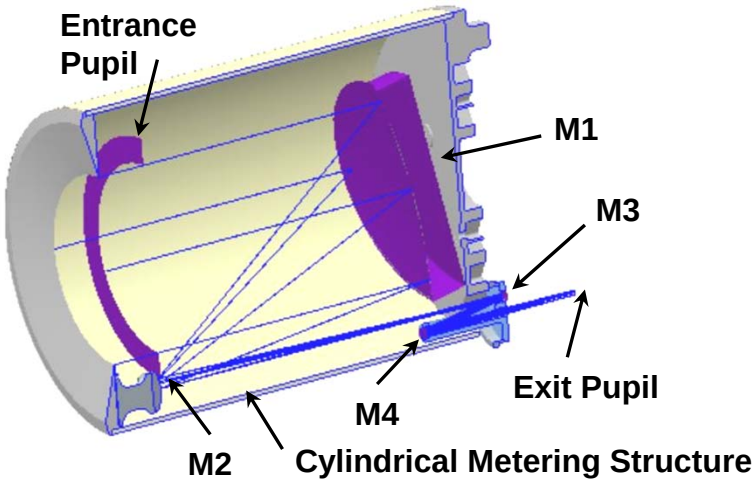
Objectives and Key Challenges:

- Design, fabricate, and test a lightweight eLISA telescope design in a flight-like environment and demonstrate the ability to satisfy mission requrements for a low scattered light and high dimensional stability in time for selection for the eLISA L3 Mission Opportunity
- Key Challenge 1: dimensional stability
- Key Challenge 2: stray light performance

Significance of Work:

- First demonstration of a validated scattered light model combined with a previous demonstration of dimensional stability will provide a firm basis for a realistic engineering model design for a flight-qualifiable telescope.
- Potential technology contribution to L3

Modified Off-axis Design



Approach:

- Use requirements developed for existing telescope
- Modify based on experience (e.g. exit pupil tilt)
- Merge a high thermal conductivity material in a simple symmetric mechanical configuration with a low-scatter optical design
- Fabricate and test for compliance with specifications

Key Collaborators:

- Code 551/Optics: Joe Howard/Garrett West/Peter Blake/Len Seals/Ron Shiri/ and Vincent Bly/553
- Code 543/Mechanical: John Crow/Justin Ward
- UF; Prof Guido Mueller

Currently Funded Period of Performance:

- Oct 2015 – Sept 2017

Recent Accomplishments:

- Nov 2015: Preliminary optical model
- Nov 2015: Preliminary stray light model
- Nov 2015: Preliminary mechanical model

Key Milestones:

- Nov 13, 2015: design preparation/initiate purchase
- Feb 19, 2016: Award contract
- Jan 24, 2017: Telescope delivery
- Jul 20, 2017: demonstrate low scatter performance
- Sep 30, 2017: demonstrate optical pathlength stability

Application:

- Flagship gravitational wave missions (eLISA)
- Laser ranging and/or communications
- precision metrology applications

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

Planar Antenna-Coupled Superconducting Detectors for CMB Polarimetry

PI: James Bock/JPL

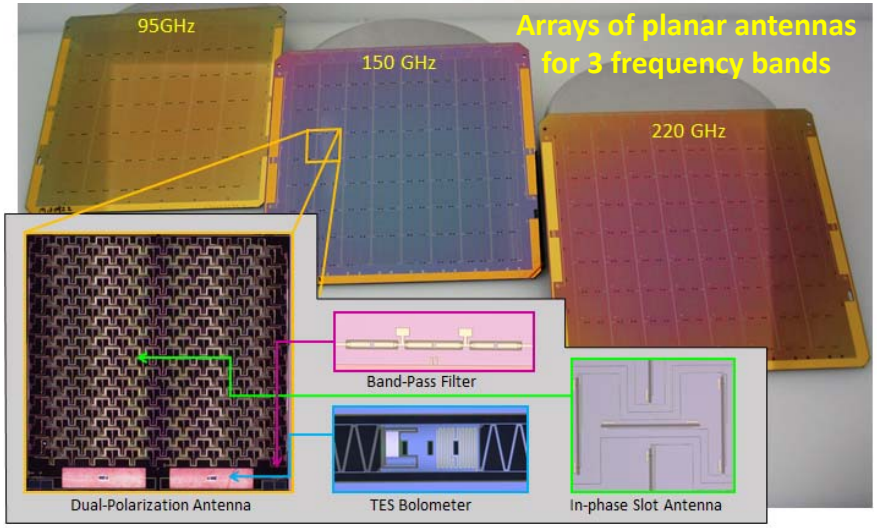
Objectives and Key Challenges:

Advance antenna-coupled superconducting detector technologies for space requirements:

- RF propagation properties
- Beam control and polarized matching
- Extended-frequency antennas
- Detectors stability and cosmic-ray response
- Readout-noise stability
- Modular focal-plane units

Significance of Work:

- Antenna designs for all bands required by the Inflation Probe
- Detector sensitivity, stability, and minimized particle susceptibility appropriate for space-borne observations



Approach:

- Planar antennas provide entirely lithographed fabrication with no coupling optics
- 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, and Alexis Weber (JPL)
- Jon Hunacek, Howard Hui, and Sinan Kefeli (Caltech)
- Chao-Lin Kuo (Stanford), Jeff Filippini (UICU)

Current Funded Period of Performance:

Jan 2014 – Dec 2015; Jan 2016 – Dec 2017

Recent Accomplishments:

✓ 90- and 150-GHz focal planes flew on SPIDER balloon experiment
✓ Fabricated 40-GHz antennas; fielded 220-GHz arrays
✓ Tested tapered antennas with refracting optical system
✓ Tested beam-line particle response to frame events in Planck device

Next Milestones:

- Test 40-GHz antenna
- Develop second-generation wide-band antenna
- Develop second-generation dual-color antenna

Applications:

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

TRL_{In} = **3-4** $TRL_{Current}$ = **3-6** TRL_{Target} = **4-6**