Program Technology Gaps

A Presentation to the Mirror Tech 2015 Workshop
Bernard D. Seery and Thai Pham

November 10, 2015
Annapolis, Maryland

Presentation Content

This talk will discuss the span of highest priority technologies for both astrophysics programs

- what the top technology need categories are
- competed lines available
- what we are already funding
Astrophysics Has 3 Science Themes

• **Physics of the Cosmos (PCOS)**
  - How does the universe work? How do matter, energy, space, and time behave under the extraordinary diverse conditions of the cosmos?
  - Program Office resides at GSFC

• **Cosmic Origins (COR)**
  - How did we get here? How did the universe originate and evolve to produce the galaxies, stars, and planets we see today?
  - Program Office resides at GSFC

• **Exoplanet Exploration (ExEP)**
  - Are we alone? What are the characteristics of planetary systems orbiting other stars, and do they harbor life?
  - Program Office resides at JPL

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**Physics of the Cosmos**

**Science Objectives**

- Expand our knowledge of dark energy
- Precisely measure the cosmological parameters governing the evolution of the universe and test the inflation hypothesis of the Big Bang
- Test the validity of Einstein's General Theory of Relativity and investigate the nature of spacetime
- Understand the formation and growth of massive black holes and their role in the evolution of galaxies
- Explore the behavior of matter and energy in its most extreme environments
Cosmic Origins
Science Goals

- Improve understanding of the many phenomena and processes associated with:
  - galaxy formation and evolution
  - stellar formation and evolution
  - planetary system formation and evolution
  - from the earliest epochs to today
COR MISSIONS

OPERATING

HST 1990 –

COR NASA missions finished (in varying states of rollup)

Spitzer 2003 –

WISE

Prime mission operations completed 2011; data deliveries from prime mission completed late 2013.

Herschel

Operations ended 6/28/2013

GALEX

Turned off 4/13/2013; data refinements continue to 2017.

SOFIA

NASA's Astrophysics Division funds the development of technology at all levels of maturity.

- The Astrophysics Research and Analysis (APRA) program funds technology development in the earliest phases, from basic research through the first feasibility demonstrations (typically Technology Readiness Level (TRL) 1 through 3).

- The Strategic Astrophysics Technology (SAT) program matures technologies that address the needs of a specific future mission, taking them from the feasibility demonstration to a lab demonstration of a design that meets specific performance requirements (TRL 3 to 6).

- The final maturation stages (TRL 6 through 9) focus on proving the technology’s flight-worthiness for a mission-specific application. These stages are addressed by incorporating the technology into a flight project’s implementation plan.
Strategic Technology Investment Sequence

1. Prioritize science  
   Decadal Survey
2. Identify technology gaps  
   Community input
3. Prioritize gaps  
   Technology Management Board (TMB)
4. Select and invest  
   NASA HQ Astrophysics

Strategic Technology Development Process

Process is responsive to community input and informs strategic technology investments for the program and beyond.
Program Annual Technology Report (PATR)

- The PATR supports Program technology development planning
- Provides overview of the Program and summarizes its technology development activities over the prior year
- Gives status of Program strategic technology development and announces new SAT award selections
- Summarizes technology gaps submitted by the community
- Provides a prioritized list of technology gaps for the coming year to inform the SAT proposal call and selection decisions

2015 PCOS and COR PATRs

Available at Program websites (pcos.gsfc.nasa.gov and cor.gsfc.nasa.gov)
Overview of Technology Gap Identification and Prioritization Process

- The community identifies technology gaps each June
  - by working with the Program Analysis Group (PAG) or through direct individual submission to the Program Office
- The Technology Management Board (TMB) reviews and prioritizes the community identified technology gaps in July
  - TMB membership includes senior members of NASA HQ Astrophysics Division and its Program Offices, and as required, independent subject matter expert(s) from the community
  - Technology gaps prioritization is based on a published set of criteria that addresses scientific priorities, benefits and impacts, scope of applicability, and timeliness
- The technology gaps and resulting priorities are published in the Program Annual Technology Report (PATR), released each October

Objectives and Purposes of Technology Gap Prioritization

- **Objectives**
  - Identify technology gaps applicable and relevant to Program strategic objectives as described in the Astrophysics Implementation Plan (AIP)
  - Rank these technology gaps, recommending investment priorities
- **Purposes**
  - Inform the SAT solicitation and other NASA technology development programs (APRA, SBIR, and other OCT and STMD activities)
  - Inform technology developers of Program technology gaps to help focus efforts
  - Inform selection of technology awards to be aligned with Program goals and science objectives
  - Improve transparency and relevance of Program technology investments
  - Inform the community and engage it in our technology development process
  - Leverage technology investments of external organizations by defining our strategic technology gaps and identifying NASA as a potential customer
### PCOS 2015 Technology Gaps Prioritization

<table>
<thead>
<tr>
<th>Priority</th>
<th>PCOS Capability Gaps</th>
<th>Science</th>
<th>Compared to 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High-power, narrow-line-width laser sources</td>
<td>GW</td>
<td>Same</td>
</tr>
<tr>
<td>1</td>
<td>Highly stable low-divergence light sources</td>
<td>GW</td>
<td>Same</td>
</tr>
<tr>
<td>1</td>
<td>Large-format, high-spectral-resolution, small-pixel X-ray focal plane arrays</td>
<td>X-ray</td>
<td>Same</td>
</tr>
<tr>
<td>1</td>
<td>Affordable, lightweight, high-resolution X-ray optics</td>
<td>X-ray</td>
<td>Same</td>
</tr>
<tr>
<td>1</td>
<td>Advanced millimeter-wave focal plane arrays for CMB polarimetry</td>
<td>IP</td>
<td>Same</td>
</tr>
<tr>
<td>1</td>
<td>High-efficiency cooling systems for temperatures covering the range 20 K to below 1 K</td>
<td>IP, X-ray</td>
<td>Same</td>
</tr>
<tr>
<td>2</td>
<td>Phase measurement subsystem (PMS)</td>
<td>GW</td>
<td>Same</td>
</tr>
<tr>
<td>2</td>
<td>Millimeter-wave optical elements</td>
<td>IP</td>
<td>Same</td>
</tr>
<tr>
<td>2</td>
<td>Low-mass, low-noise X-ray imaging array with moderate spectral resolution</td>
<td>X-ray</td>
<td>Same</td>
</tr>
<tr>
<td>2</td>
<td>High-efficiency X-ray grating arrays for high-resolution spectroscopy</td>
<td>X-ray</td>
<td>Same</td>
</tr>
<tr>
<td>2</td>
<td>Gravitational reference sensor (GRS)</td>
<td>GW</td>
<td>New</td>
</tr>
<tr>
<td>3</td>
<td>Very wide field focusing instrument for time domain X-ray astronomy</td>
<td>X-ray</td>
<td>New</td>
</tr>
<tr>
<td>3</td>
<td>Ultra-high-resolution focusing X-ray observatory telescope</td>
<td>X-ray</td>
<td>New</td>
</tr>
<tr>
<td>3</td>
<td>Advanced X-ray polarimeter sensitivity with the use of negative ion gas</td>
<td>X-ray</td>
<td>New</td>
</tr>
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<td>3</td>
<td>Fast few-photon UV detectors</td>
<td>UHECR</td>
<td>New</td>
</tr>
<tr>
<td>3</td>
<td>Lightweight, large-area reflective optics</td>
<td>UHECR</td>
<td>New</td>
</tr>
<tr>
<td>3</td>
<td>Low-power time-sampling readout</td>
<td>UHECR</td>
<td>New</td>
</tr>
<tr>
<td>3</td>
<td>Low-power comparators and logic arrays</td>
<td>UHECR</td>
<td>New</td>
</tr>
<tr>
<td>3</td>
<td>Lattice optical clock for Solar Time Delay mission and other applications</td>
<td>STD</td>
<td>New</td>
</tr>
<tr>
<td>3</td>
<td>High-performance gamma-ray telescope</td>
<td>G-ray</td>
<td>Same</td>
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</tbody>
</table>

### COR 2015 Technology Gaps Prioritization

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<thead>
<tr>
<th>Priority</th>
<th>COR Capability Gaps</th>
<th>Science</th>
<th>Compared to 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Large-format, low-noise and ultralow noise far-infrared (FIR) direct detectors</td>
<td>F-IR</td>
<td>Was 2</td>
</tr>
<tr>
<td>1</td>
<td>Band-shaping and dichroic filters for the UV/Vis</td>
<td>UVOIR</td>
<td>Was 2</td>
</tr>
<tr>
<td>1</td>
<td>Heterodyne FIR detector arrays and related technologies</td>
<td>F-IR</td>
<td>Was 2</td>
</tr>
<tr>
<td>1</td>
<td>High-QE, rad-hard, large-format, non-phonon-counting UVOIR detectors</td>
<td>UV</td>
<td>Same</td>
</tr>
<tr>
<td>1</td>
<td>Photon-counting large-format UV detectors</td>
<td>UV</td>
<td>Same</td>
</tr>
<tr>
<td>1</td>
<td>High-efficiency UV multi-object spectrometers</td>
<td>UV</td>
<td>Same</td>
</tr>
<tr>
<td>1</td>
<td>High-reflectivity mirror coatings for UV/Vis/NIR</td>
<td>UVOIR</td>
<td>Same</td>
</tr>
<tr>
<td>2</td>
<td>Affordable, lightweight, ultra-stable, large-aperture telescopes</td>
<td>UVOIR</td>
<td>Was 1</td>
</tr>
<tr>
<td>2</td>
<td>Large, cryogenic, FIR telescopes</td>
<td>F-IR</td>
<td>Was 3</td>
</tr>
<tr>
<td>2</td>
<td>Sensing and control at the nanometer level or better</td>
<td>UVOIR</td>
<td>Was 1</td>
</tr>
<tr>
<td>2</td>
<td>Advanced cryo-coolers</td>
<td>F-IR, X-ray,</td>
<td>Was 3</td>
</tr>
<tr>
<td>2</td>
<td>Thermally Stable Telescope</td>
<td>UVOIR, Hab Ex</td>
<td>New</td>
</tr>
<tr>
<td>2</td>
<td>Disturbance isolation</td>
<td>UVOIR, Hab Ex</td>
<td>New</td>
</tr>
<tr>
<td>2</td>
<td>FIR interferometer</td>
<td>F-IR</td>
<td>Was 3</td>
</tr>
<tr>
<td>2</td>
<td>High-performance, sub-Kelvin coolers</td>
<td>F-IR, X-ray</td>
<td>Same</td>
</tr>
<tr>
<td>3</td>
<td>Affordable monolithic telescope mirror technologies</td>
<td>UV</td>
<td>New</td>
</tr>
<tr>
<td>3</td>
<td>Photon-counting visible and NIR detector arrays</td>
<td>UVOIR</td>
<td>Was 2</td>
</tr>
<tr>
<td>3</td>
<td>Very-large-format, high-QE, low-noise, radiation-tolerant detectors for the UV/Vis/NIR</td>
<td>UVOIR</td>
<td>Was 2</td>
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<tr>
<td>3</td>
<td>Wide-bandwidth, high-spectral-dynamic-range receiving system</td>
<td>Cosmic Dawn</td>
<td>Same</td>
</tr>
<tr>
<td>3</td>
<td>Sensing and control at the picometer level</td>
<td>Hab Ex</td>
<td>New</td>
</tr>
</tbody>
</table>
### PCOS SAT Portfolio

<table>
<thead>
<tr>
<th>Funding Source</th>
<th>Technology Development Title</th>
<th>Principal Investigator</th>
<th>Org</th>
<th>Start Year and Duration</th>
<th>TRL</th>
<th>Science Area</th>
<th>Tech Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAT2010</td>
<td>Directly-Deposited Blocking Filters for Imaging X-ray Detectors</td>
<td>Mark Baudz</td>
<td>MIT</td>
<td>FY2012, 4 years</td>
<td>5</td>
<td>X-ray Detectors</td>
<td></td>
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<tr>
<td>SAT2011</td>
<td>Colloidal Microspheres Propellant Feed System for Gravity Wave Astrophysics Missions</td>
<td>John Zhang</td>
<td>JPL</td>
<td>FY2013, 3 years</td>
<td>5</td>
<td>Propulsion</td>
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<tr>
<td>SAT2011</td>
<td>Advanced Laser Frequency Stabilization</td>
<td>John Lipe</td>
<td>Stanford</td>
<td>FY2013, 3 years</td>
<td>5</td>
<td>Lasers</td>
<td></td>
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<tr>
<td>SAT2011</td>
<td>Telescope for a Space-based Gravitational Wave Mission</td>
<td>Jeffrey Lewis</td>
<td>GSFC</td>
<td>FY2013, 3 years</td>
<td>5</td>
<td>GW Telescope</td>
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<tr>
<td>SAT2011</td>
<td>Demonstrating Enabling Technologies for the High-Resolution Imaging Spectrometer of the Next NASA X-ray Astronomy Mission</td>
<td>Caroline Kilbourne</td>
<td>GSFC</td>
<td>FY2013, 3 years</td>
<td>4</td>
<td>X-ray Telescope</td>
<td></td>
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<tr>
<td>SAT2012</td>
<td>Advanced Antenna-Coupled Superconducting Detector Arrays for CMB Polarity</td>
<td>James Bock</td>
<td>JPL</td>
<td>FY2014, 2 years</td>
<td>3</td>
<td>CMB Detectors</td>
<td></td>
</tr>
<tr>
<td>SAT2012</td>
<td>Phase Measurement System Development for Interferometric Gravitational Wave Detectors</td>
<td>William Klapstein</td>
<td>JPL</td>
<td>FY2014, 3 years</td>
<td>4</td>
<td>GW Photometers</td>
<td></td>
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<tr>
<td>SAT2012</td>
<td>Demonstration of a TRL 5 Laser System for eLISA</td>
<td>Joel Ullom</td>
<td>NIST</td>
<td>FY2014, 3 years</td>
<td>3</td>
<td>GW Lasers</td>
<td></td>
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<tr>
<td>SAT2013</td>
<td>Technology Development for an AC-Multiplexed Calorimeter for ATHENA</td>
<td>Jordan Camp</td>
<td>GSFC</td>
<td>FY2014, 2 years</td>
<td>3</td>
<td>X-ray Detectors</td>
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<tr>
<td>SAT2013</td>
<td>Fast Event Recognition for the ATLAST Wide Field Imager</td>
<td>David Rindus</td>
<td>PSU</td>
<td>FY2015, 3 years</td>
<td>3</td>
<td>X-ray Detectors</td>
<td></td>
</tr>
<tr>
<td>SAT2013 &amp; SAT2010</td>
<td>Reflection Grating Modules: Alignment and Testing</td>
<td>Randy McElhany</td>
<td>U. of Iowa</td>
<td>FY2015, 2 years</td>
<td>4</td>
<td>X-ray Optics</td>
<td></td>
</tr>
<tr>
<td>SAT2013 &amp; APRA2011</td>
<td>Development of 0.5 Arc-second Adjustable Grazing Incidence X-ray Mirrors for the SMART-X Mission Concept</td>
<td>Paul Reid</td>
<td>SAO</td>
<td>FY2015, 3 years</td>
<td>3</td>
<td>X-ray Optics</td>
<td></td>
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<tr>
<td>SAT2013 &amp; SAT2011</td>
<td>Monostatic and Lightweight High-Resolution X-ray Optics</td>
<td>William Zhang</td>
<td>GSFC</td>
<td>FY2015, 2 years</td>
<td>5</td>
<td>X-ray Optics</td>
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<tr>
<td>SAT2013 &amp; SAT2010</td>
<td>Advanced Packaging for Critical Angle X-ray Transmission Gratings</td>
<td>Mark Schattenburg</td>
<td>MIT</td>
<td>FY2015, 3 years</td>
<td>4</td>
<td>X-ray Optics</td>
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<tr>
<td>SAT2014</td>
<td>High Efficiency Feedhorn-Coupled TES-based Detectors for CMB Polarization Measurements</td>
<td>Edward Wolfe</td>
<td>GSFC</td>
<td>FY2016, 3 years</td>
<td>3</td>
<td>CMB Detectors</td>
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<tr>
<td>SAT2014 &amp; APRA2011</td>
<td>Telescope Dimensional Stability Study for a Space-based Gravitational Wave Mission</td>
<td>Jeffrey Livas</td>
<td>GSFC</td>
<td>FY2016, 2 years</td>
<td>3</td>
<td>GW Telescope</td>
<td></td>
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<tr>
<td>SAT2014 &amp; SAT2012</td>
<td>Superconducting Antenna-Coupled Detectors and Readouts for Space-Borne CMB Polarity</td>
<td>James Bock</td>
<td>JPL</td>
<td>FY2016, 2 years</td>
<td>3</td>
<td>CMB Detectors</td>
<td></td>
</tr>
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<th>Science Area</th>
<th>Tech Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAT2010</td>
<td>High performance cross-strip micro-channel plate detector systems for spaceflight experiments.</td>
<td>John Vallerga</td>
<td>UCB</td>
<td>FY2012, 4 years</td>
<td>4</td>
<td>UV Detectors</td>
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<tr>
<td>SAT2010</td>
<td>2D-15μm enhanced MgF2 and LiF Over-coated Al Mirrors for FUV Space Astronomy</td>
<td>Manuel Quijada</td>
<td>GSFC</td>
<td>FY2012, 4 years</td>
<td>4</td>
<td>UV Optical Coatings</td>
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<tr>
<td>SAT2011</td>
<td>Kinetic Inductance Detector Imaging Arrays for Far-Infrared Astrophysics</td>
<td>Jonas Zmuidzinas</td>
<td>JPL</td>
<td>FY2013, 3 years</td>
<td>3</td>
<td>Far-IR Detectors</td>
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<tr>
<td>SAT2011</td>
<td>Ultraviolet coatings, materials and processes for advanced telescope optics</td>
<td>Kunjipatham Balasubramanian</td>
<td>JPL</td>
<td>FY2013, 3 years</td>
<td>3</td>
<td>Optical Coatings</td>
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<td>SAT2011</td>
<td>High Efficiency Detectors in Photon Counting and Large Field Arrays for Astrophysics Missions</td>
<td>Shouleh Nikzad</td>
<td>JPL</td>
<td>FY2013, 4 years</td>
<td>4</td>
<td>UV Optical Detectors</td>
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<tr>
<td>SAT2012</td>
<td>A Far-Infrared Heterodyne Array Receiver for Cil and Oil Mapping</td>
<td>Imran Mehdi</td>
<td>JPL</td>
<td>FY2014, 3 years</td>
<td>4</td>
<td>Far-IR Detectors</td>
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<tr>
<td>SAT2012 &amp; SAT2010</td>
<td>Deployment of Digital Micromirror Device (DMD) Arrays For Use In Future Space Missions</td>
<td>Zoran Ninkov</td>
<td>RTI</td>
<td>FY2014, 3 years</td>
<td>4</td>
<td>UV Spectroscopy</td>
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<td>SAT2014 &amp; SAT2011</td>
<td>Advanced Mirror Technology Development Phase 2</td>
<td>Phil Stahl</td>
<td>GSFC</td>
<td>FY2014, 4 years</td>
<td>3</td>
<td>UV/VIR Detectors</td>
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<td>SAT2014</td>
<td>Raising the Technology Readiness Level of 4.7-THz local oscillators</td>
<td>Qing Hu</td>
<td>MIT</td>
<td>FY2016, 3 years</td>
<td>3</td>
<td>Far-IR Detectors</td>
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<tr>
<td>SAT2014 &amp; SAT2010</td>
<td>Building a Better ALD - use of Plasma Enhanced ALD to Construct Efficient Interference Filters for the FUV</td>
<td>Paul Scowen</td>
<td>ASU</td>
<td>FY2016, 3 years</td>
<td>3</td>
<td>UV Optical Coatings</td>
<td></td>
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<tr>
<td>SAT2014 &amp; SAT2010</td>
<td>Development of Large Area (100x100 mm) photon counting UV detectors</td>
<td>John Vallerga</td>
<td>UCB</td>
<td>FY2016, 4 years</td>
<td>3</td>
<td>UV Detectors</td>
<td></td>
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<tr>
<td>SAT2014 &amp; SAT2012</td>
<td>Advanced FUV/VUV/Visible Photon Counting and Ultraviolet Noise Detectors</td>
<td>Shouleh Nikzad</td>
<td>JPL</td>
<td>FY2016, 3 years</td>
<td>3-4</td>
<td>CMB Detectors</td>
<td></td>
</tr>
</tbody>
</table>
Structural Dynamics of Large Space Structures

Optomechanical Stability:
Data indicate large mirrors are stable over nanometer dimensions if designed to be so.

For advanced coronography, N - 10 pm piston errors Segment – to – segment are tolerated for contrasts of $10^{-10}$ - $10^{-11}$.

New Diagnostics Needed
pm interferometer
pm stimulus
pm – level isolation

PCOS Priority 1
Optics related technology needs

- Stable, low stray light telescopes for gravitational wave detection
  Athermal telescope designs have to be developed to meet stability and alignment requirements. Materials have to be tested for creep at the pm/nrad level. Study ways to predict and minimize the effects of back scatter on interferometry.

- Long life lasers
  2W laser in a linear polarized, single frequency, single spatial mode. It requires fast actuators (BW > 10kHz) for intensity and frequency stabilization to enable laser phase locking and relative intensity noise of <10-6/rtHz. Shot noise limited at 1mW laser power above 2 MHz, and 10 year lifetime.

- Lightweight replicated X-ray optics
  Requirement for perfectly aligned primary-secondary mirror pair are 3.3-6.6 arc-sec HPD for 5-10 arc-sec HPD mission, respectively. Manufacturability requirements drive fabrication yield and fabrication time per mirror segment.

Bernie, you had this page in your draft so I left it in – not sure if or where it fits in this presentation.
**PCOS Priority 2**  
**Optics related technology needs**

- **High resolution X-ray gratings**  
  - High ruling density off-plane (OP) reflective and critical angle transmission (CAT) x-ray gratings for dispersive x-ray spectroscopy. Gratings with resolving power λ/Δλ > 3000 over wavelengths of 1.2 to 5 nm.

- **High throughput, cold mm-wave telescope operating at low background for future inflation probe missions**  
  - High-throughput telescope and optical elements with controlled polarization properties are required; possible use of active polarization modulation using optical elements.

- **Phasemeter system for gravitational wave measurement**  
  - The phasemeter measures the phase of laser beat signals with $\text{ucycl/rtHz}^{??}$ sensitivity. It is the main interferometry signal for LISA. The phasemeter consists of a fast photo receiver which detects the beat signal, an ADC which digitizes the laser beat signal, and a digital signal processing board which processes the digitized signal.

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**COR Priorities 1 & 2**  
**Optics related technology needs**

- **Priority 1**  
  - **UV Coatings** – highly reflective and highly uniform with wide bandpasses UV coatings are required to support the next generation of UV missions, accommodate multiple reflections, and accommodate combined UV and high-contrast exoplanet imaging objectives.

- **Priority 2**  
  - **Large low cost, light-weight precision mirrors for ultra-stable large aperture UV optical telescopes**
  
  Future UV/Optical telescopes will require increasingly large apertures to answer the questions raised by HST, JWST, Planck and Herschel and to complement ground-based telescopes. Requires technologies that provide high degree of thermal and dynamic stability, and wave front sensing and control.
How You Can Participate and Contribute

- Contribute and engage with your science community!
- Visit the PCOS and/or COR website for more information
- Subscribe to the PCOS and/or COR mailing list and receive news and announcements to stay informed
- Attend PAG meetings (in person or by phone)
- Participate in PAG activities
- Contribute to technology gaps list by submitting input(s)
- Propose to SAT proposal calls
  - Notices of Intent to propose are due January 22, 2016
  - Proposals are due March 18, 2016
- Feel free to contact us if you have any questions
  pcos.gsfc.nasa.gov
  cor.gsfc.nasa.gov

Conclusion

- PCOS and COR Program Offices solicit input on technology gaps each June from the community
  - Technology gaps prioritization is determined by the Program TMB, using a stringer of prioritization criteria that includes the scientific priorities, benefits, and impacts, scope of applicability, and timeliness
- Technology gap priorities are published each October in the PATR.
  - This information informs the call for SAT proposals
  - Informs technology developers of the Program needs
  - Guides the selection of technology awards to be aligned with program goals
- Contribute and engage with your science community
  - Submit technology gaps
  - Participate in PAG meetings and activities
  - Be informed of the program needs – consult the PATRs
  - Propose your innovation
Thanks for Listening

QUESTIONS?

Backups
The Program Analysis Groups (PAGs)

- There are three PAGs
  - Physics of the Cosmos PAG – PhysPAG
  - Cosmic Origins PAG – COPAG
  - Exoplanet Exploration PAG – ExoPAG
- Each of the three themed PAGs serves as a forum for soliciting and coordinating input and analysis from the scientific community in support of their respective program objectives.
- PAGs are constituted by the NASA Astrophysics Subcommittee and their responsibilities include collecting and summarizing community input with subsequent reporting to NASA via the NASA Advisory Council (NAC)
- All interested scientists and technologists can contribute to the PAG’s functions by participating in the PAG meetings and by providing inputs.

PAGs serve as the voice of the community

Notable Development Successes

- **WFIRST/AFTA** adopted the H4RG NIR detector to address some of the most enduring questions in astrophysics (early 2020s launch)
- Advancement in X-ray microcalorimeter detector provides meaningful contribution to **ATHENA** (2028 launch)
- TES bolometer detector selected to support the **SOFIA HAWC** instrument (2015 deployment)
- High reflectivity UV coating advancement implemented on optics for **ICON** and **GOLD** Explorer missions (2017 launches)
- Antenna-coupled transition-edge superconducting bolometer technology deployed by **BICEP2** (2014)
- **REXIS**, an MIT student instrument on **OSIRIS-Rex**, incorporating Program-funded directly-deposited X-ray blocking filter technology on its engineering and flight CCDs (2016 launch)
New

**COR:**
- Successful on-sky demonstration of kinetic inductance detector (KID) array system at Caltech Submillimeter Observatory (CSO) (2013);
- TES bolometer detector was selected to support the SOFIA HAWC instrument (2015 deployment);
- High-efficiency Solid-state Photon-counting Ultraviolet Detector (SPUD) will be flight-tested on the balloon experiment FIREBall (2015 launch).
- High-reflectivity UV coating advancement were used to coat optics for ICON and GOLD Explorer missions (2017 launches); and
- WFIRST/AFTA study has adopted the H4RG NIR detector to address some of the most enduring questions in astrophysics (mid-2020 launch);

New

**PCOS:**
- Advancements made to X-ray mirror and detector/readout technologies is allowing meaningful NASA contribution to ATHENA (2028 launch);
- REXIS, an MIT student instrument on OSIRIS-Rex, is incorporating Program-funded directly-deposited X-ray blocking filter technology on its engineering and flight CCDs (2016 launch); and
- Antenna-coupled transition-edge superconducting (TES) bolometer technology was deployed in the ground-based BICEP2 experiment to measure B-mode polarization, and performance-tested in a realistic environment on SPIDER’s 2014/15 Antarctic season long-duration balloon flight.
Notable Development Successes

- WFIRST/AFTA adopted the H4RG NIR detector to address some of the most enduring questions in astrophysics (early 2020s launch)
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### SAT Selection Rates

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### Strategic Technology Development Model

- **Identify** strategic technology gaps by prioritizing community-provided inputs, recommending those developments that best support Astrophysics Implementation Plan (AIP) (Decadal Survey) priorities
- **Invest** in technology development via peer-reviewed ROSES SAT process
- **Monitor** development and maturation of funded technologies
- **Support** mission concepts in formulation with guidance of Technology Development Plans/Roadmaps
- **Enable or enhance** future flight missions by supporting infusion of newly-matured technologies
Strategic Technology Development Model

• Following are Paul’s charts (if he uses what Mario/we provided), we’ll ask for a copy when he is done

Next Level of Detection in Astrophysics

Obstacles:
- Policy (priorities, budgets, strategy, implementation)
- Technology (gaps and anticipated needs)

Challenging Areas:
- Detectors
- Optics and Coatings
- Mirrors and Support Structures
- High-efficiency cooling systems
### Detectors (across wavelengths)

Increase efficiency, SNR, resolution, and speed
- Increase QE (>80-90%)
- Large format and high pixel count
- Radiation tolerant
- Photon-counting
- Low-power and fast readout
- Low read-noise
- Low dark current

### Optics and Coatings

Improve system throughput, image quality, and information collected
- High contrast imaging (10^-6)
- Wavefront control
- High spectral and angular resolution X-ray optics
- X-ray polarimeters
- X-ray grating arrays
- Multi-object devices (digital micro-mirror and micro-shutters)
- Coatings (reflective/UV-Vis, antireflective/far-IR, and low-stress/X-ray optics)
- Dichroic filters
- Interferometers
Mirrors and Structures
Improve stability, performance, and efficiency of light collection
- Advanced X-ray mirror technologies
- UVOIR mirror materials
- Ultra stability (sensing and control from micrometers, nanometers to picometers)
- Nano composite materials (~ zero CTE)
- Actuators
- Metrology (lasers and measuring techniques)

High-efficiency cooling systems
Improve efficiency and heat-lift at ultralow temperatures
- High-performance sub-Kelvin coolers
- Advanced cryo-coolers
- Solid-state coolers