PCOS Physics of the Cosmos Program
COR Cosmic Origins Program

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

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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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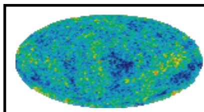
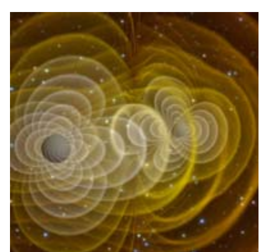


Physics of the Cosmos Science Objectives

- **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**

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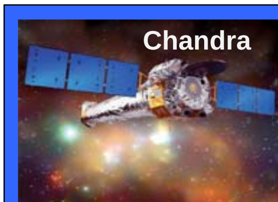
PCOS MISSIONS

OPERATING | **RELATED**



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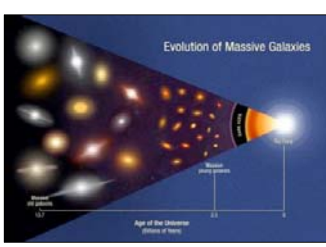
Cosmic Origins Science Goals

- **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



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COR MISSIONS

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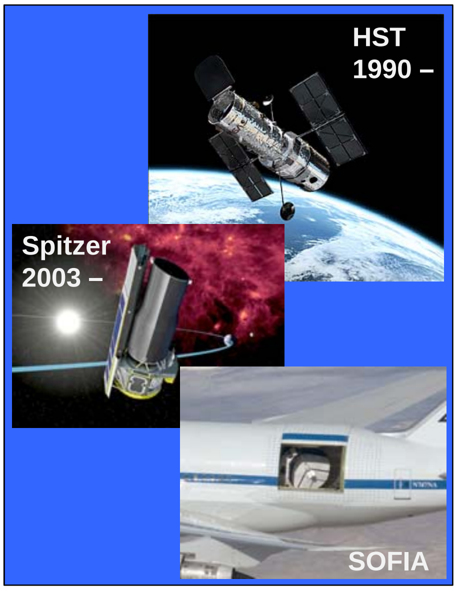

COR NASA missions finished (in varying states of rollup)

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Astrophysics Funds All Levels of Technology Development

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.**

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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

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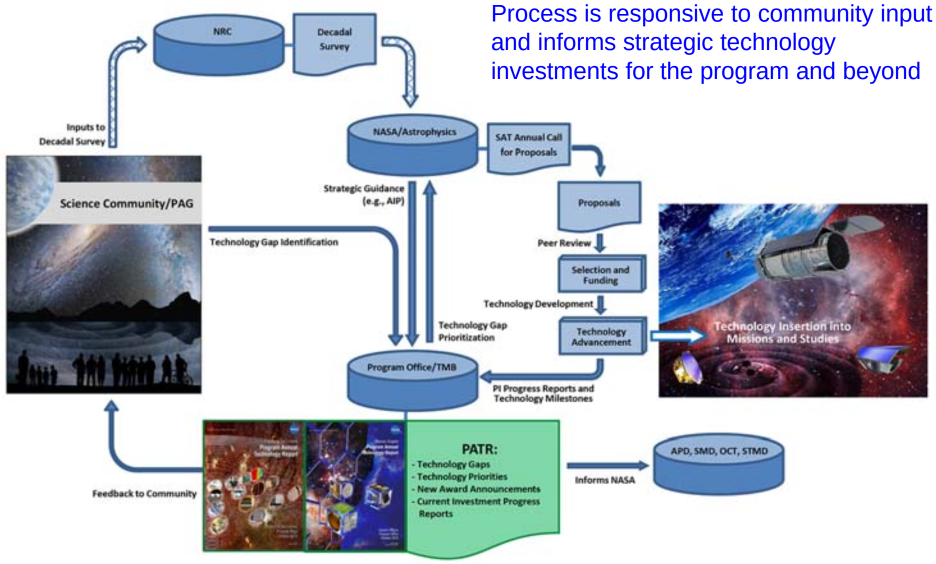
Strategic Technology Development Process

Process is responsive to community input and informs strategic technology investments for the program and beyond



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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

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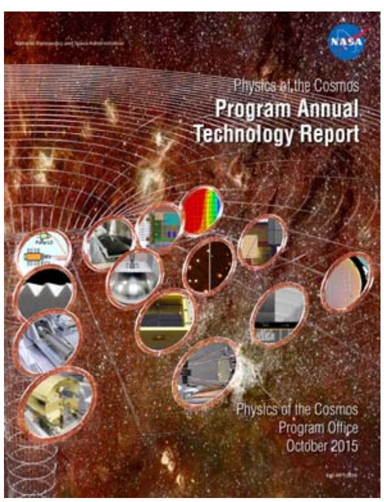
2015 PCOS and COR PATRs



Available at Program websites (pcos.gsfc.nasa.gov and cor.gsfc.nasa.gov)

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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**

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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

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PCOS 2015 Technology Gaps Prioritization

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

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COR 2015 Technology Gaps Prioritization

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

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PCOS SAT Portfolio

Funding Source	Technology Development Title	Principal Investigator	Org	Start Year and Duration	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	Colloid Microthruster Propellant Feed System for Gravity Wave Astrophysics Missions	John Ziemer	JPL	FY2013, 2 years	5	GW	Propulsion
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	Advanced Antenna-Coupled Superconducting Detector Arrays for CMB Polarimetry	Jamie Bock	JPL	FY2014, 2 years	3	CMB	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

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COR SAT Portfolio

Funding Source	Technology Development Title	Principal Investigator	Org	Start Year and Duration	TRL	Science Area	Tech Area
SAT2010	High performance cross-strip micro-channel plate detector systems for spaceflight experiments.	John Vallerga	UCB	FY2012, 4 years	4	UV	Detectors
SAT2010	20:15Enhanced MgF2 and LiF Over-coated Al Mirrors for FUV Space Astronomy	Manuel Quijada	GSFC	FY2012, 3 years	4	UV	Optical Coatings
SAT2011	Kinetic Inductance Detector Imaging Arrays for Far-Infrared Astrophysics	Jonas Zmuidzinas	JPL	FY2013, 3 years	3	Far-IR	Detectors
SAT2011	Ultraviolet coatings, materials and processes for advanced telescope optics	Kunjithapatham Balasubramanian	JPL	FY2013, 3 years	3	UV	Optical Coatings
SAT2011	High Efficiency Detectors in Photon Counting and Large Focal Plane Arrays for Astrophysics Missions	Shouleh Nikzad	JPL	Fy2013, 3 years	4	UV, Optical	Detectors
SAT2012	A Far-Infrared Heterodyne Array Receiver for CII and OI Mapping	Imran Mehdi	JPL	FY2014, 3 years	4	Far-IR	Detectors
SAT2012	Deployment of Digital Micromirror Device (DMD) Arrays For Use In Future Space Missions	Zoran Ninkov	RIT	FY2014, 2 years	4	UV	Spectroscopy
SAT2012 & SAT2010	Advanced Mirror Technology Development Phase 2	Phil Stahl	MSFC	FY2014, 3 years FY2012, 3 years	3	UVOIR	Optics
SAT2014	Raising the Technology Readiness Level of 4.7-THz local oscillators	Qing Hu	MIT	FY2016, 3 years	3	Far-IR	Detectors
SAT2014	Building a Better ALD - use of Plasma Enhanced ALD to Construct Efficient Interference Filters for the FUV	Paul Scowen	ASU	FY2016, 3 years	3	UV	Optical Coatings
SAT2014 & SAT2010	Development of Large Area (100x100 mm) photon counting UV detectors	John Vallerga	UCB	FY2016, 2 years	4	UV	Detectors
SAT2014 & SAT2011	Advanced FUVUV/Visible Photon Counting and Ultralow Noise Detectors	Shouleh Nikzad	JPL	FY2016, 3 years	3 - 4	UVOIR	Detectors

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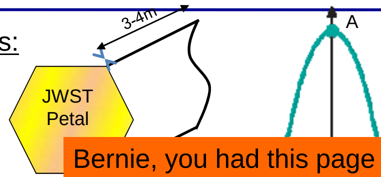
Structural Dynamics of Large Space Structures

nm Dynamics:

Three Orders Of Magnitude

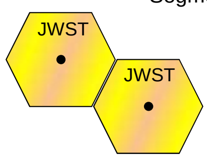


Bernie, you had this page in your draft so I left it in – not sure if or where it fits in this presentation

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

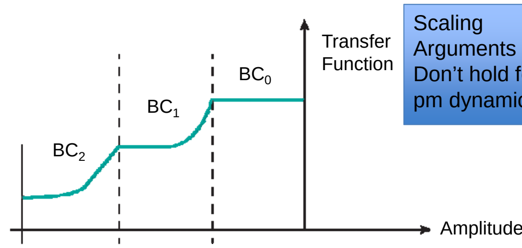
pm Dynamics:

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



New Diagnostics Needed

pm interferometer
pm stimulus
pm – level isolation



Scaling Arguments Don't hold for pm dynamics

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 ... y.

This page needs updating to 2015's priority 1

- **Long life laser**
  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.

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 lamb
    This page needs updating to 2015's priority 2
    › 5 nm.
- **High throug … g 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 ***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 miss … sses, and accomm … naging objectiv
    This page needs updating to 2015's priority 1 and 2 (add second page as needed
- **Priority 2**
  - Large low cost, light-weight precision mirrors for ultra-stable large aperture UV optical telescopes
  - Deployable light-weight precision mirrors for future very 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.

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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

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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 stringen… …c priorities, benefits…
- **Technolog… …he PATR. This infor…**

Rewrite for this event/audience?

  - Informs t…
  - 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

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Thanks for Listening

QUESTIONS?

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Backups

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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 t

e 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

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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)**

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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);

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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.

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Notable Development Successes

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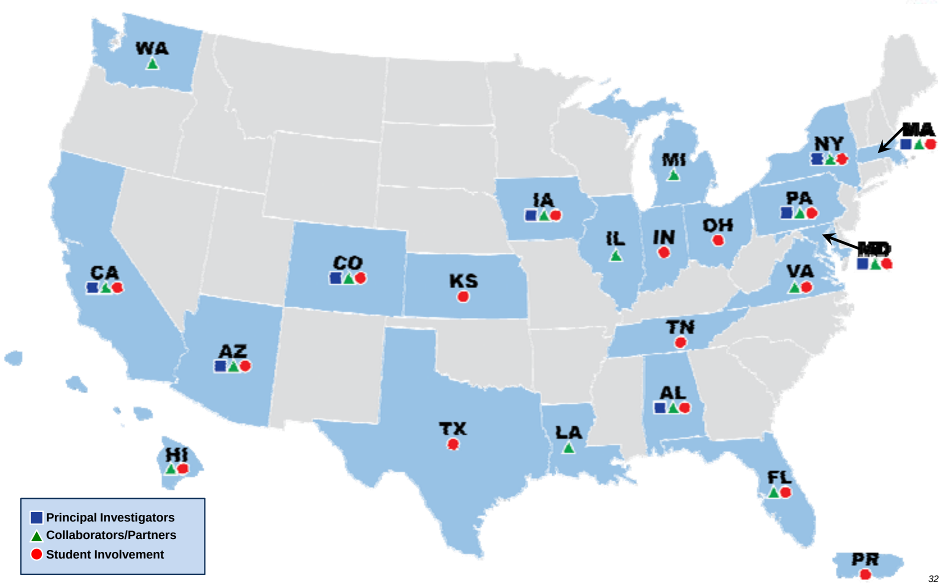
SAT Impact Geographical Distribution



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SAT Selection Rates

Solicitation year	TPCOS Proposals		Selection Rate
	Submitted	Awarded	
2010	21	5	24%
2011	26	5	19%
2012	10	3	30%
2013	8	6	75%
2014	6	3	50%
Total to Date	71	22	31%

Solicitation year	TCOR Proposals		Selection Rate
	Submitted	Awarded	
2010	14	3	21%
2011	24	5	21%
2012	13	3	23%
2013	Not solicited	N/A	N/A
2014	14	4	29%
Total to Date	65	15	23%

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

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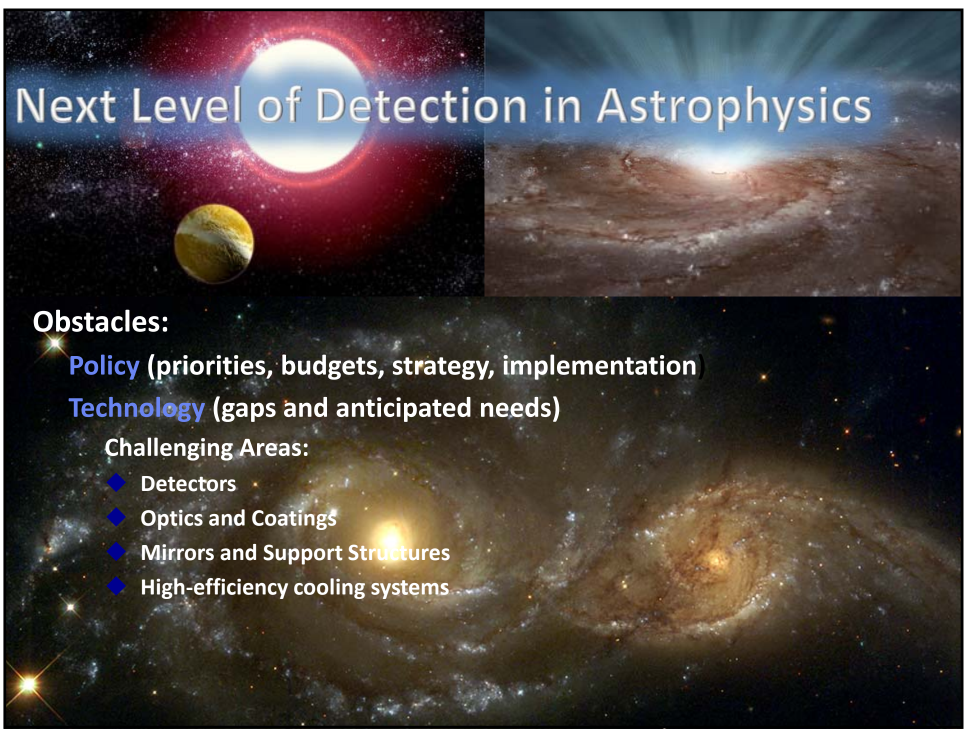
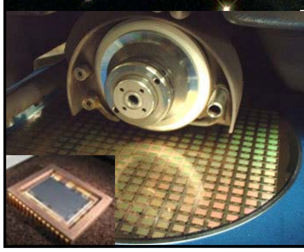
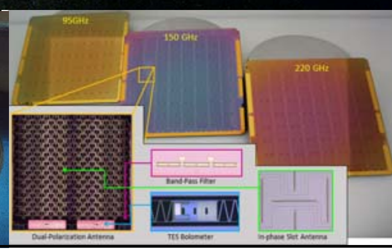


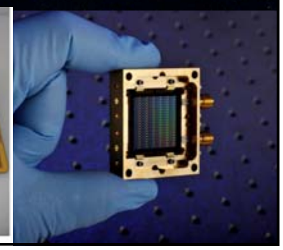
Detectors (across wavelengths)

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



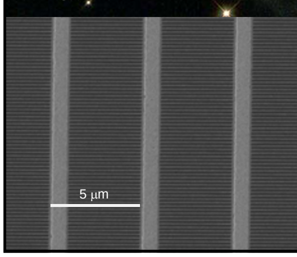


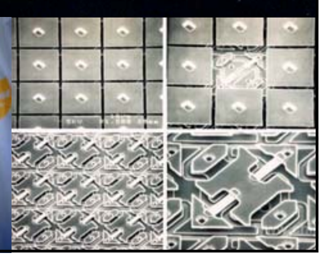


Optics and Coatings

Improve system throughput, image quality, and information collected

- High contrast imaging (10^{-10})
- 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

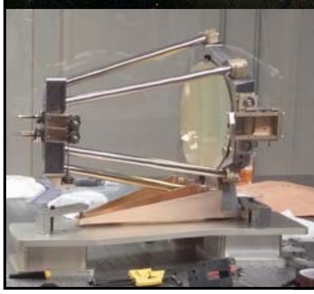
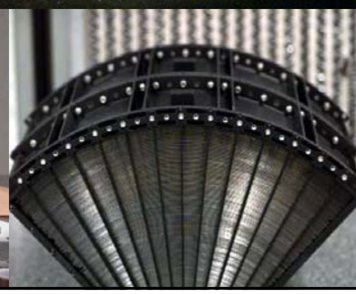
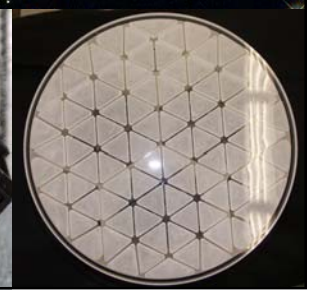




Mirrors and Structures

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