Mirror Technologies for NASA Astrophysics Missions

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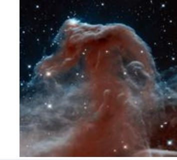
Albuquerque, November 18, 2014

The NASA science program will continue to make great discoveries and be a source of pride and inspiration for the Nation – and the world

Why Astrophysics?

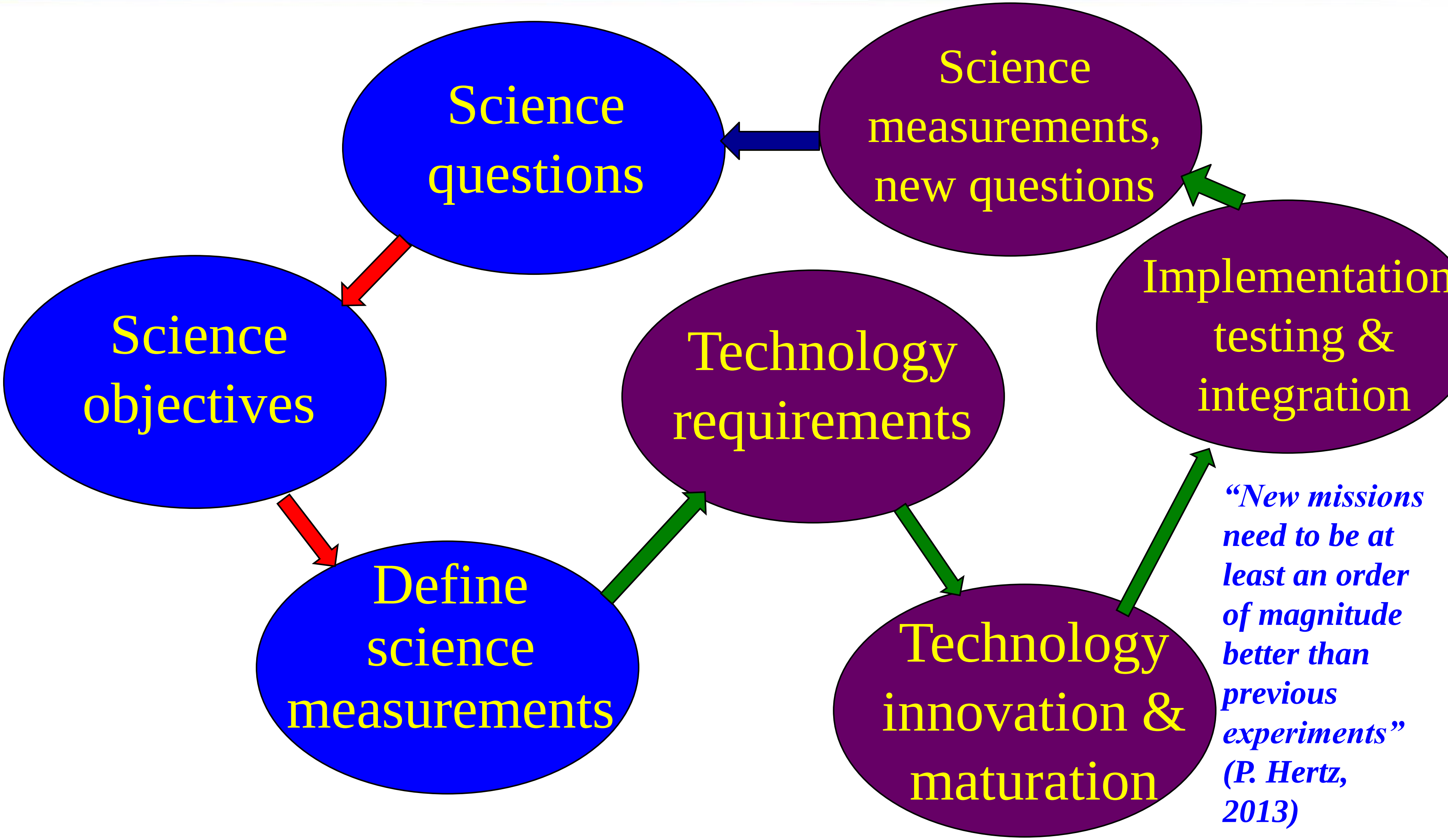
- Astrophysics is a **photon starved** discipline, demanding high performance from all systems and subsystems utilized for on-sky observations and detections.
- Most of the low-hanging fruit science goals, including synoptic astronomical observations have been explored and exploited.
- New science efforts and techniques such as *persistent time domain observations, high contrast imaging, diffraction limited mapping, high spatial and spectral resolution data, and wide field surveys* will open up new discovery spaces with important breakthroughs.
- New wavelength regimes and major gains in sensitivity also lead to significant new discoveries

Why Technology?



- The next level of detection in astrophysics will only be achieved with better and disruptive technology solutions.
  - Our main stumbling block is **NOT** a scientific one; we have enough compelling scientific questions, mission concepts, theory and simulations predictions, data pipelines and science archives.
  - Technology roadmaps will continue to identify important subsystems, techniques and materials needed to advance our science understanding.
  - **Optical science improvements** are possible and are key in the detection of the origins of the Universe and in the search for life.
  - New advances in material sciences, mirror design, fabrication, polishing, and metrology will enable future missions to achieve the next level of detection.

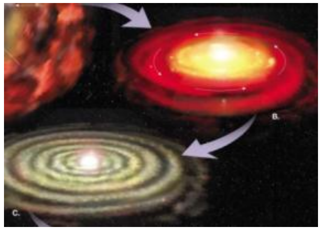
Science Flow and Mapping



"New missions need to be at least an order of magnitude better than previous experiments" (P. Hertz, 2013)

Astrophysics Science Themes

- The organization of NASA's Astrophysics Division includes three science themes or program areas:



How did we get here? ➔ *Cosmic Origins Program (COR)* ***– GSFC Program Office***

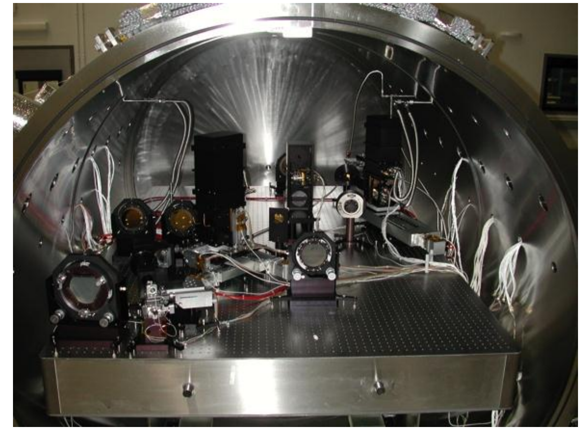
Are we alone? ➔ *Exoplanet Exploration Program (EXEP)* ***– JPL Program Office***

How does the universe work? ➔ *Physics of the Cosmos (PCOS)* ***– GSFC Program Office***

Strategic Astrophysics Technology (SAT)

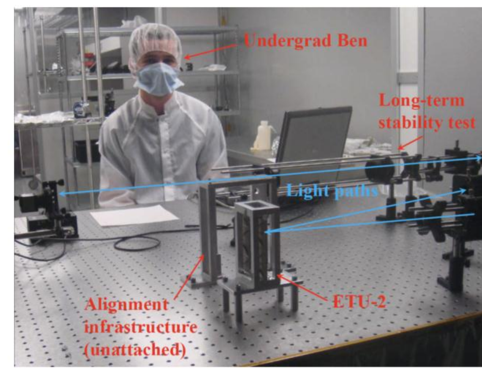
- Introduced in 2009, the ***Strategic Astrophysics Technology (SAT)*** Program was established to support the maturation of mid-range Technology Readiness Level (TRL) technologies developed and tested in the laboratory (TRL ≤ 3) to a point where they can be incorporated into flight missions with an acceptable level of risk (TRL ~ 5-6).
- Similarly, the SAT program is organized into 3 elements, one for each of the Division's science themes:
  - *Technology Development for the Cosmic Origins Program (TCOR).*
  - *Technology Development for Exoplanet Missions (TDEM)*
  - *Technology Development for the Physics of the Cosmos Program (TPCOS)*

Strategic Astrophysics Technology (SAT)



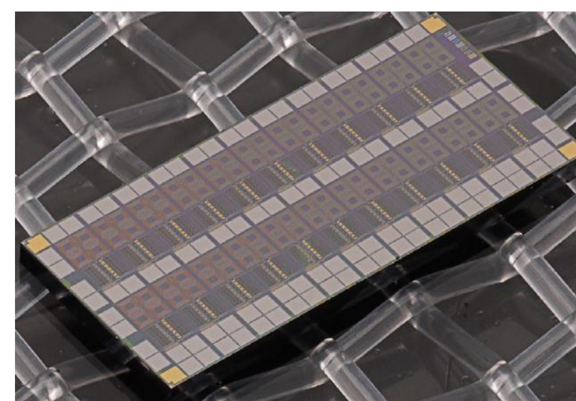
Areas of emphasis:

- TDEM
  - *Starlight Suppression Demonstrations*
  - *Wavefront Sensing and Control of Scattered Light*
  - *System Performance Assessment*



- TPCOS
  - *Technologies for X-ray Astrophysics*
  - *Technologies for Gravitational Astrophysics*
  - *Technologies for CMB Polarization Measurements*

- TCOR
  - *Next Generation Detectors*
  - *Optical Coatings*
  - *Precision Large Optics*



Technology Areas and Steps

- Technology **innovation** and **readiness**!

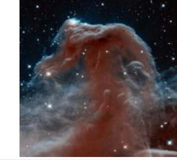
(discovery) (implementation)

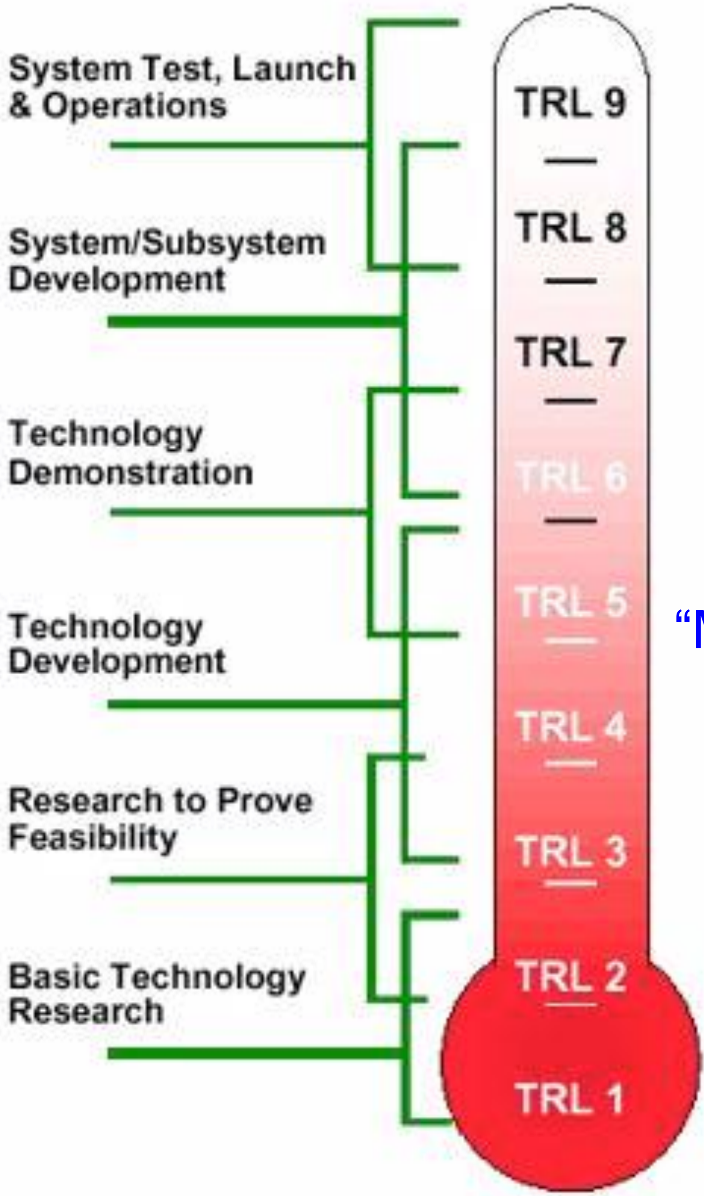
(inception) (maturation)

Areas of Emphasis

- Optics (high contrast imaging, lightweight mirrors deployable mirrors, large collecting areas, perfect wavefront corrections)
- Electronics (high QE of detectors, low noise readouts, large format detectors, superconductors)
- Material sciences (coatings, lightweight structures, actuators, strong materials)

Technology Readiness Levels





Flight Ready Hardware
(6 ≤ TRL ≤ 9)

Challenge:
“Mid-TRL Gap”

SAT Program
3 ≤ TRL ≤ 5

APRA (1 ≤ TRL ≤ 3+)

SAT Selected Proposals in Themes

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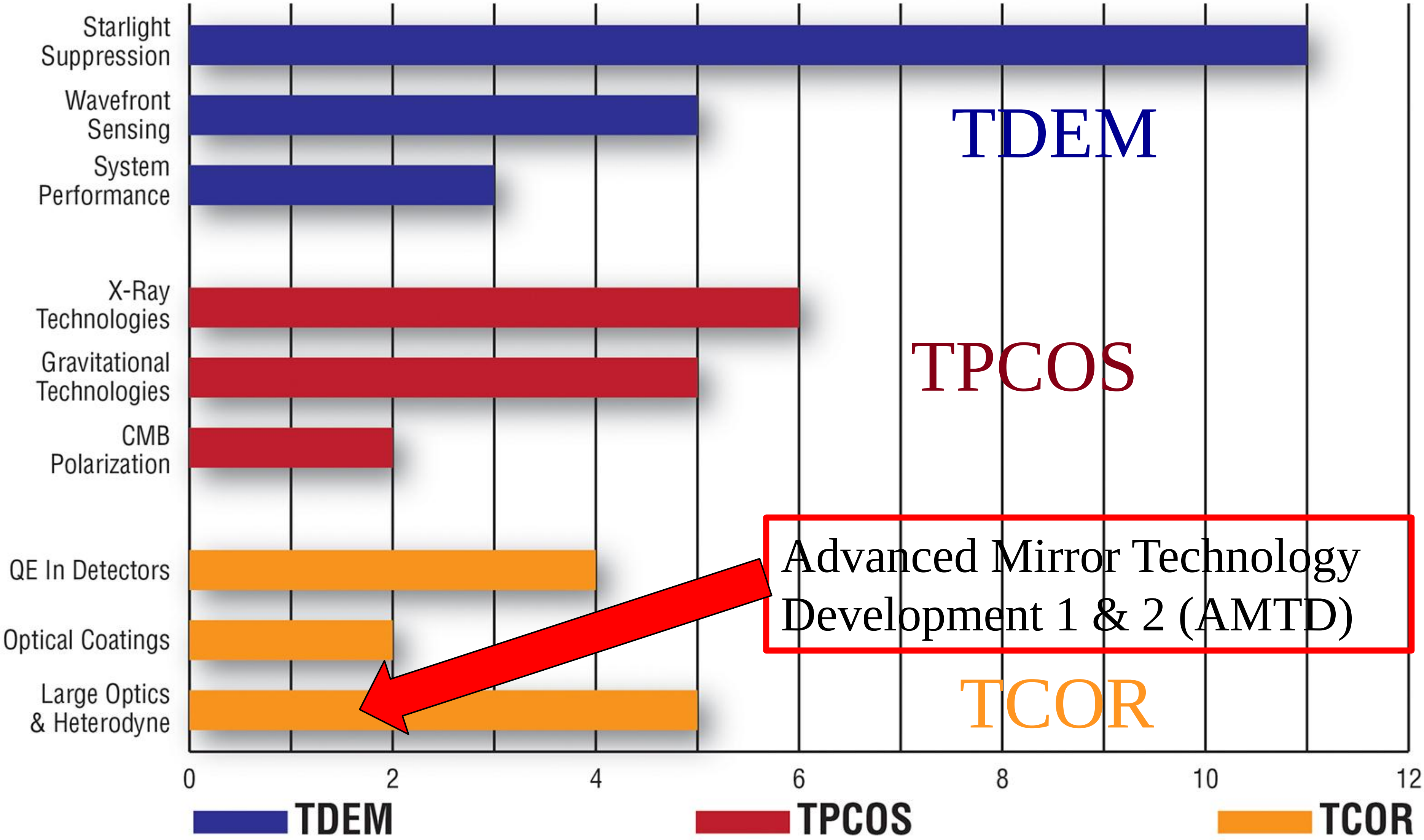
NASA Headquarters



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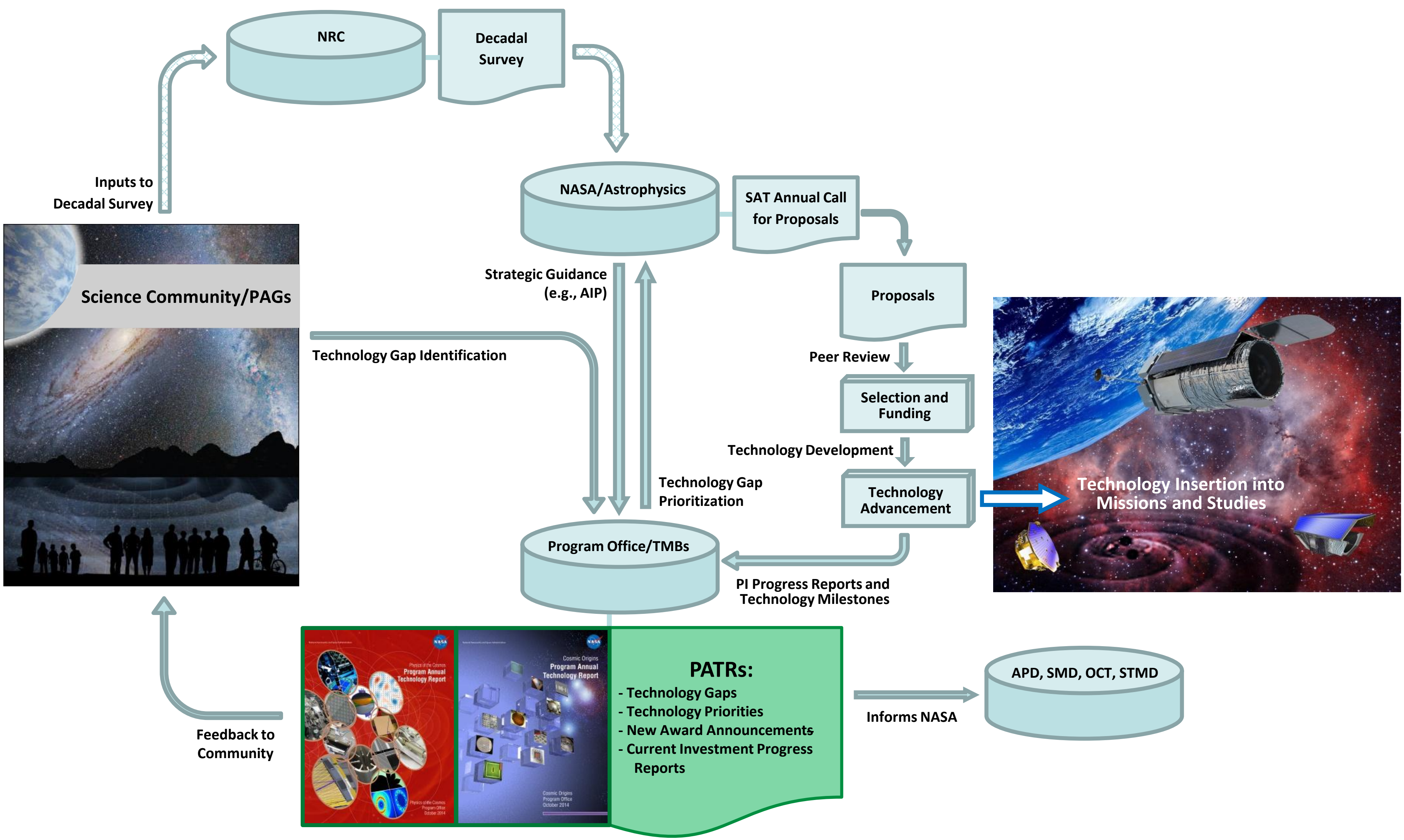
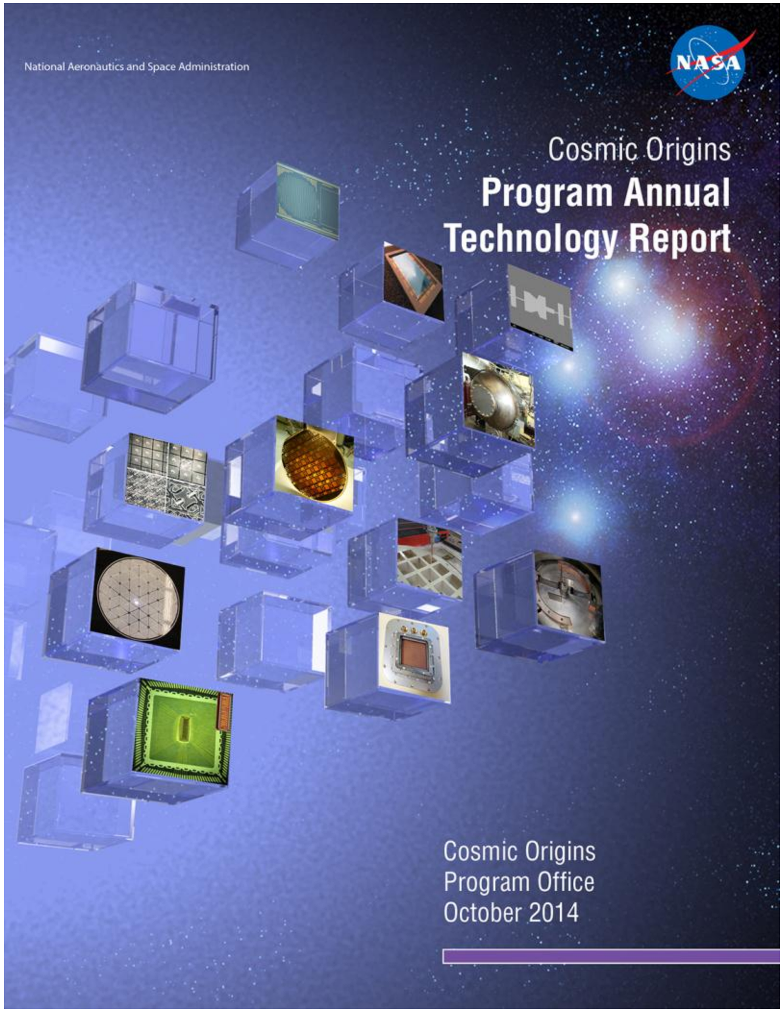
Program Technology Management



Program Annual Technology Reports

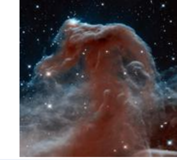
PCOS

COR



Additional information about the PCOS and COR technology development programs can be found in the PATRs which can be downloaded from their respective websites: http://pcos.gsfc.nasa.gov and http://cor.gsfc.nasa.gov

ExEP Technology Plan Appendix



JPL Document D-81562

TDEM

Exoplanet Exploration Program
Technology Plan

Appendix: 2013

P. R. Lawson

National Aeronautics and
Space Administration

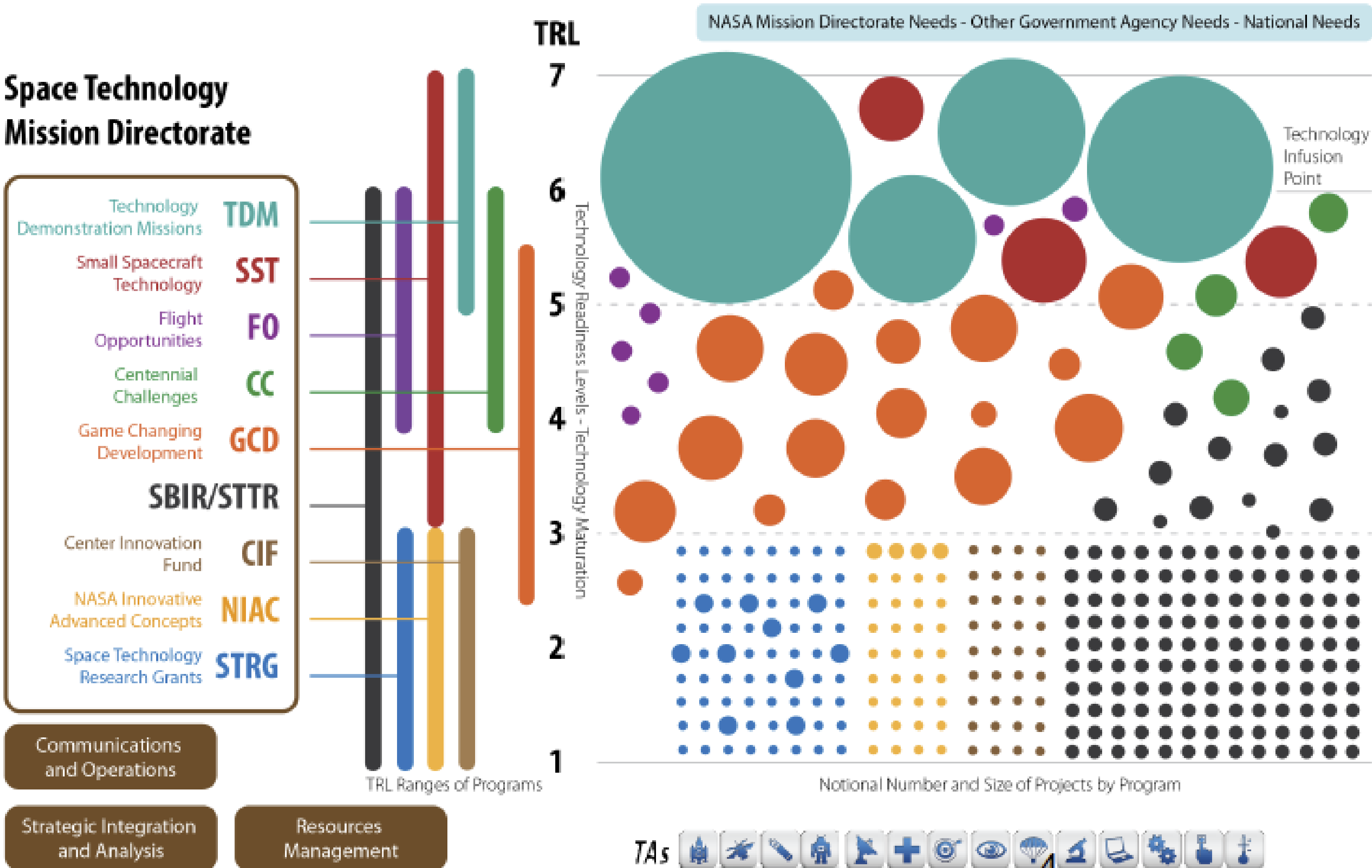
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

21 January 2014

The Exoplanet Exploration Program issues an annual appendix to the Program's Technology Plan. The appendix updates ongoing technology development efforts supported by the program as well as technology gaps and programmatic priorities. The latest technology plan appendix can be downloaded at: http://exep.jpl.nasa.gov/technology/.

The next edition of the appendix is expected to be released by mid-January. Prospective SAT/TDEM proposers are strongly encouraged to review the appendix before preparing their proposals.

Space Technology Portfolio



Space Technology Mission Directorate Contributes to Astrophysics

Space Technology Mission Directorate

*FY13 budget; STMD supports other Science Divisions & HEOMD.

NIAC
Center Innovation Fund
Space Tech Res Grants
$45M*

Small Business Innovative Research (SBIR)/
Small Business Technology Transfer (STTR)
$165M*

Game Changing Development
$151M*

Small Spacecraft
$15M*

Tech Demo Missions
$184M*

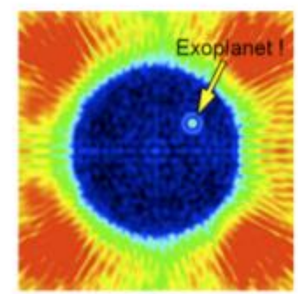
SMD Astrophysics Division

APRA

SAT

1 2 3 4 5 6 7

TRL



WFIRST

STMD Early Stage Innovation (ESI)

2014 ESI Topic 3: Optical Coatings and Thin-film physics

(UV & Far-IR coatings)

$1 \leq$ TRL ≤ 3

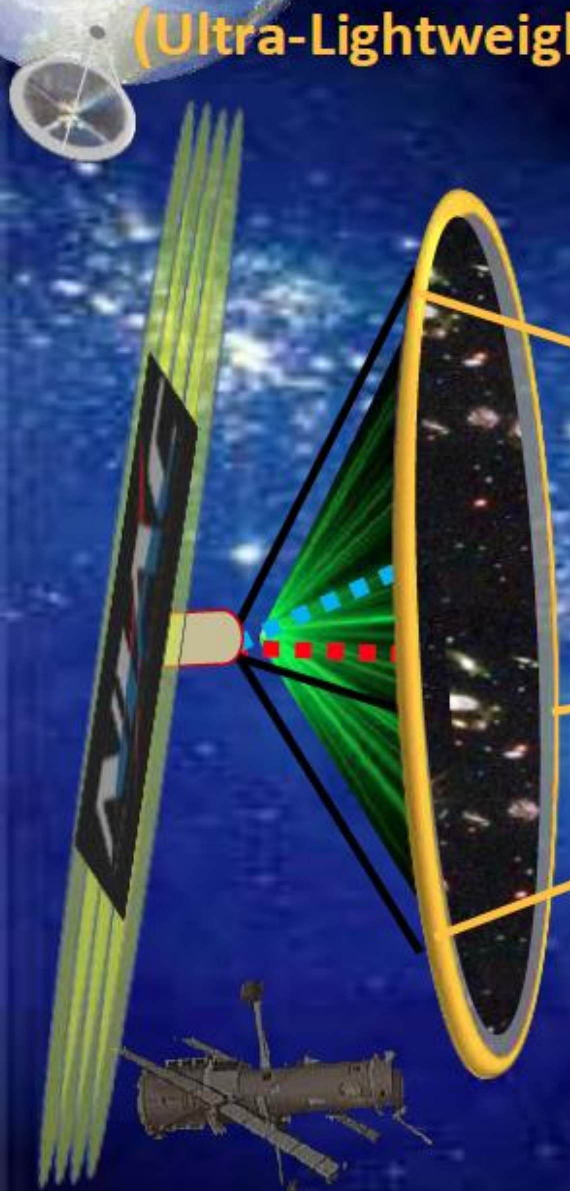
Proposals: 11

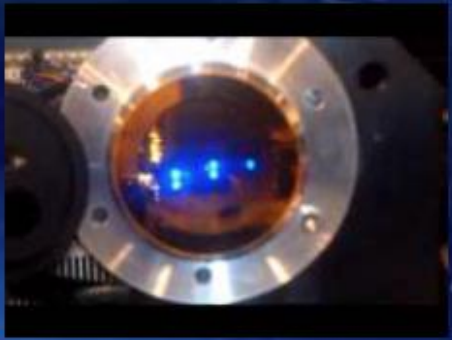
Selected: 2 ($250K/year/grant)

Announced: 25 Sept 2013

OCCAMS: Optically Controlled & Corrected Active Meta-material Space Structures

(Ultra-Lightweight Photonic Muscle Space Structures, Phase II)





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ASTRONOMY

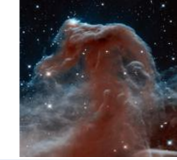
Na Kilo

Past Space Missions

Retired Space-based COR Mission Mirrors

Telescope	Size (m)	Material	Type	No. Elem.	Wavelength Range	Coating
Herschel	3.5	SiC	Monolithic	-	57 – 670m	Al
Planck	1.5 x 1.9	C-fiber+plastic	Monolithic	-	0.3 – 11mm	Al
GALEX	0.5	Fused silica	Monolithic	-	1340-2830Å	Al:MgF_2
FUSE	4 x 0.39 x 0.35	Zerodur, lightweight	Multiple Monolithic	4	905-1187Å	SiC, Al:LiF
HUT	0.9	Zerodur	Monolithic	-	825 -1850Å	Ir/Os/SiC
WISE	0.4	Al	Monolithic	-	3-12m	Au
ISO	0.6	Fused silica	Monolithic	-	2.4-240m	Au
AKARI	0.7	SiC + CVD	Monolithic	-	2-180m	Au, ZnS
COBE/DIRBE	0.2	Aluminum	Monolithic	-	1.25-240m	Ni + Au
IRAS	0.6	Beryllium	Monolithic	-	8-120m	Al

Current and Future Missions



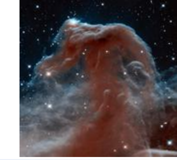
Current Space-based COR/ExEP Mission Mirrors

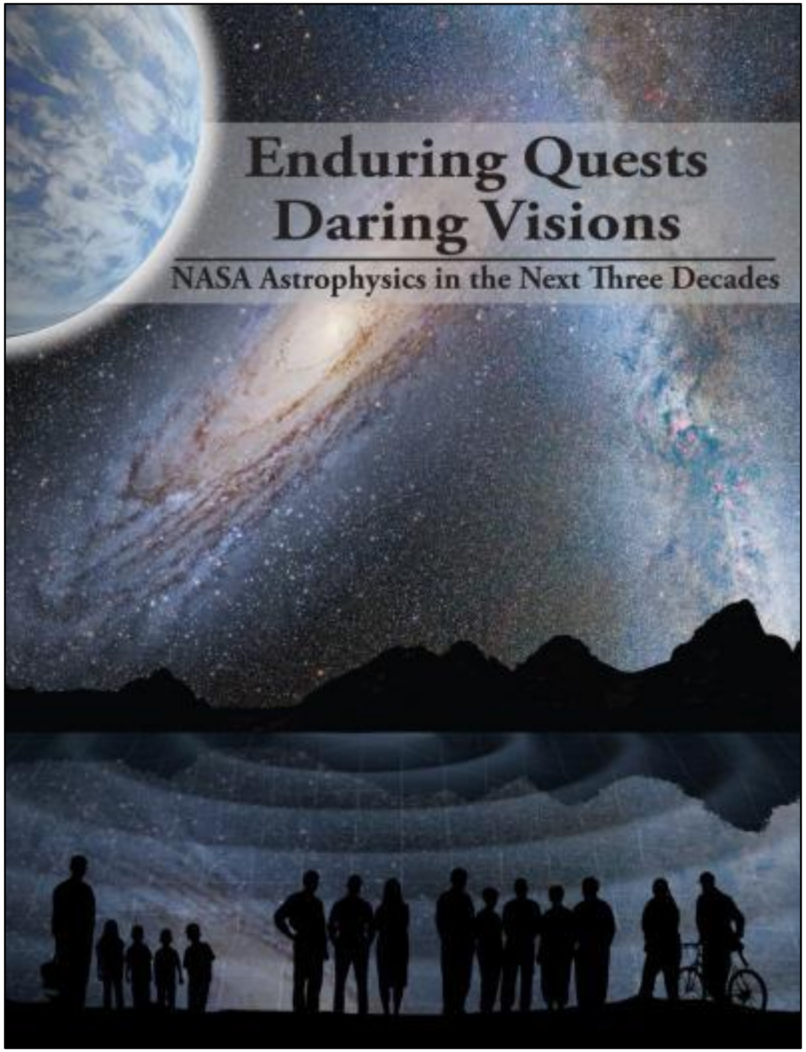
Telescope	Size (m)	Material	Type	No. Elem.	Wavelength Range	Coating
Kepler	1.3	ULE Glass	Monolithic	-	4000-8650Å	Ag
Hubble	2.4	ULE Glass, fused Si, honeycomb	Monolithic	-	1150Å – 2.5m	Al:MgF2
Spitzer	0.85	Be	Monolithic	-	3 – 180m	Al
SOFIA	2.7	Zerodur	Monolithic	-	0.3 – 655m	Al
Swift UVO	0.3	Zerodur	Monolithic	-	1700-6000Å	MgF2

Future Space-based COR Mission Mirrors

Telescope	Size (m)	Material	Type	No. Elem.	Wavelength Range	Coating
JWST	6.5	Beryllium	Segmented	18	0.6-18m	Au
WFIRST	2.4	ULE glass, lightweighted	Monolithic	-	0.4-10m	?
Euclid	1.2	SiC or Zerodur	Monolithic	-	0.55-2m	?
SPICA	3.5	SiC	Monolithic	-	30-200m	?
Sub-Orbital Payloads						
Rockets	0.55	Glass	Monolithic	-	Varies	Varies
Balloons	0.5-1.0	Glass	Monolithic	-	Varies	Varies

Astrophysics Roadmap





- A 30 year vision to address the enduring questions:
  - Are we alone?
  - How did we get here?
  - How does the universe work?

http://science.nasa.gov/astrophysics/documents

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NASA Headquarters

Technology Needs

Formative Era Missions

	Formative Era				
	GW Surveyor	CMB-pol Surveyor	FIR Surveyor	LUVOIR Surveyor	X-ray Surveyor
Formation flying				Beneficial	
Interferometry: precision metrology	Essential		Beneficial		
X-ray interferometry					
High-contrast imaging techniques				Essential	
Optics deployment and assembly			Essential	Essential	Beneficial
Broadband coatings		Essential		Essential	
X-ray optics					Essential
Large-format detector arrays		Essential	Essential	Essential	Essential
New detector capabilities			Essential	Beneficial	Essential
Cryogenics		Essential	Essential	Beneficial	Essential

Essential Goals

Beneficial Goals

Mirrors for Future NASA Missions

- Missions at NASA respond to science needs, not to technological capabilities or availabilities.
  - Important to trace science questions to scientific measurements and then to technology requirements.
- Technology readiness is one of the major obstacles for future advancements.
- Optical materials for the mirrors of the Far-IR and UVOIR Surveyors are ***likely to be invented*** in the upcoming years.
- The Suborbital program (Balloons and Sounding Rockets) is a good stepping stone to develop expertise and capabilities. This program has tolerance for high-risk experiments.

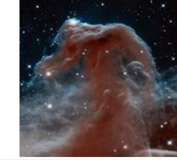
How Can You Help?

- Everyone is welcome to compete for research, innovations and maturation grants to APRA, SAT (Astrophysics) and STMD (Technology Directorate)[Next deadline is March 20, 2015]
- Become an institutional resource:
  - Volunteer for technology peer review panels
  - Technical consultants (solicitations, roadmaps, feasibility studies)
  - Join STDTs for next Decadal mission concepts
- Become a partner in mission concepts and in mission proposals [Suborbital, CubeSats, ISS, SMEX, MIDEX,….]
- Create a facility or laboratory that is unique and needed within the agency (business development investment)

Many thanks!

Questions?

Recently Completed
Planck 2013
Herschel 2013
GALEX 2013



SAT/TCOR Portfolio

Funding	Technology Development Title	PI	Institution	Start Year and Duration	Area
SAT2010	Advanced UVOIR Mirror Technology Development for Very Large Space Telescope	P. Stahl	MSFC	FY12, 3 years	Optics
SAT2010	High Performance Cross-Strip Micro-Channel Plate Detector Systems for Spaceflight Experiments	J. Vallerga	UC Berkeley	FY12, 3 years	UV Detectors
SAT2010	Enhanced MgF2 and LiF Overcoated Aluminum Mirrors for FUV Space Astronomy	M. Quijada	GSFC	FY12, 3 years	UV Coatings
SAT2011	Ultraviolet Coatings, Materials and Processes for Advanced Telescope Optics	K. Balasubramanian	JPL	FY13, 3 years	UV Coatings
SAT2011	Kinetic Inductance Detector Imaging Arrays for Far-Infrared Astrophysics	J. Zmuidzinas	JPL	FY13, 2 years	Far-IR Detectors
SAT2011	Improvements of the Performance of Near-Infrared Detectors for NASA Astrophysics Missions: Reducing the Sub-1% Detector Effects	S. Anglin	Teledyne	FY13, 1 year	UVOIR Detectors
SAT2011	H4RG Near-IR Detector Array with 10 Micron Pixels for WFIRST and Space Astrophysics	B. Rauscher	GSFC	FY13, 1 year	UVOIR Detectors
SAT2011	High Efficiency Detectors in Photon Counting and Large Focal Plane Arrays for Astrophysics Missions	S. Nikzad	JPL	FY13, 3 years	UVOIR Detectors
SAT2012	Far-Infrared Heterodyne Array Receiver	I. Mehdi	JPL	FY14, 3 years	Far-IR Detector
SAT2012	Advanced Mirror Technology Development Phase 2	P. Stahl	MSFC	FY14, 3 years	Optics
SAT2012	Development of DMD Arrays for use in Future Space Missions	Z. Ninkov	RIT	FY14, 2 years	Optics

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SAT/TDEM Portfolio

Funding	Technology Development Title	PI	Institution	Start Year and Duration	Area
TDEM2009	Visible Nulling Coronagraph Technology Maturation: High Contrast Imaging & Characterization of Exoplanets	M. Clampin	NASA GSFC	FY10, 2 years	Starlight Suppression
TDEM2009	A Photon-Counting Detector for Exoplanet Missions	D. Figer	Rochester Inst. of Tech.	FY10, 2 years	Detector Development
TDEM2009	Phase-Induced Amplitude Apodization Coronagraphy Development and Laboratory Validation	O. Guyon	U. Arizona	FY10, 2 years	Starlight Suppression
TDEM2009	Starshades for Exoplanet Imaging and Characterization: Key Technology Development	J. Kasdin	Princeton U.	FY10, 2 years	Starlight Suppression
TDEM2009	Assessing the Performance Limits of Internal Coronagraphs Through End-To-End Modeling	J. Krist	JPL	FY10, 2 years	System Modeling
TDEM2009	Advanced Speckle Sensing for Internal Coronagraphs and Methods of Isolating Exoplanets from Speckles	C. Noecker	Ball Aerospace	FY10, 2 years	Wavefront Sensing/Control
TDEM2009	Advanced Hybrid Lyot Coronagraph Technology for Exoplanet Missions	J. Trauger	JPL	FY10, 2 years	Starlight Suppression
SAT2010	Advances in Pupil Remapping (PIAA) Coronagraphy: Improving Bandwidth, Throughput and Inner Working Angle	O. Guyon	U. Arizona	FY12, 2 years	Starlight Suppression
SAT2010	Verifying Deployment Tolerances of an External Occulter for Starlight Suppression	J. Kasdin	Princeton U.	FY12, 2 years	Starlight Suppression
SAT2010	Compact Achromatic Visible Nulling Coronagraph Technology Maturation	R. Lyon	NASA GSFC	FY12, 2 years	Starlight Suppression
SAT2010	Visible Nulling Coronagraph (VNC) Technology Demonstration Program	J. Sandhu	JPL	FY12, 2 years	Starlight Suppression
SAT2010	Demonstrations of Deep Starlight Rejection with a Vortex Coronagraph	G. Serabyn	JPL	FY12, 2 years	Starlight Suppression
SAT2010	Coronagraph Starlight Suppression Model Validation: Coronagraph Milestone #3a	S. Shaklan	JPL	FY12, 2 years	System Modeling
SAT2010	Integrated Coronagraph Design and Wavefront Control Using Two Deformable Mirrors	J. Kasdin	Princeton U.	FY12, 2 years	Wavefront Sensing/Control
SAT2010	Environmental Testing Of MEMS Deformable Mirrors for Exoplanet Detection	M. Helmbrecht	Iris AO, Inc.	FY12, 2 years	Wavefront Sensing/Control
SAT2010	MEMS Deformable Mirror Technology Development for Space-Based Exoplanet Detection	P. Bierden	Boston Micromachines	FY12, 2 years	Wavefront Sensing/Control
SAT2012	Starshade Stray Light Mitigation through Edge Scatter Modeling and Sharp-Edge Materials Development	S. Casement	Northrop Grumman	FY14, 2 years	System Modeling
SAT2012	Demonstration of Starshade Starlight-Suppression Performance in the Field	T. Glassman	Northrop Grumman	FY14, 2 years	Starlight Suppression
SAT2012	Optical and Mechanical Verification of an External Occulter for Starlight Suppression	J. Kasdin	Princeton U.	FY14, 2 years	Starlight Suppression

SAT/TPCOS Portfolio

Funding	Technology Development Title	PI	Institution	Start Year and Duration	Area
SAT2010	Development of Fabrication Process for Critical-Angle X-ray Transmission Gratings	M. Schattenburg	MIT	FY12, 2 years	X-ray
SAT2010	Antenna-Coupled Superconducting Detectors for Cosmic Microwave Background Polarimetry	J. Bock	JPL	FY12, 2 years	CMB
SAT2010	Directly-Deposited Blocking Filters for Imaging X-ray Detectors	M. Bautz	MIT	FY12, 2 years	X-ray
SAT2010	Off-plane Grating Arrays for Future Missions	R. McEntaffer	U of Iowa	FY12, 2 years	X-ray
SAT2010	Development of Moderate Angular Resolution Full Shell Electroplated Metal Grazing Incidence X-ray Optics	P. Reid	SAO	FY12, 2 years	X-ray
SAT2011	Next generation X-ray Optics: High Resolution, Light Weight, and Low Cost	W. Zhang	GSFC	FY13, 2 years	X-ray
SAT2011	Demonstrating Enabling Technologies for the High-Resolution Imaging Spectrometer of the Next NASA X-ray Astronomy Mission	C. Kilbourne	GSFC	FY13, 2 years	X-ray
SAT2011	Colloid Microthruster Propellant Feed System for Gravity Wave Astrophysics Missions	J. Ziemer	JPL	FY13, 2 years	GW
SAT2011	Telescope for a Space-based Gravitational Wave Mission	J. Livas	GSFC	FY13, 2 years	GW
SAT2011	Advanced Laser Frequency Stabilization Using Molecular Gasses ** (co-funded with STMD)	J. Lipa	Stanford	FY13, 2 years	GW
SAT2012	Antenna-Coupled Superconducting Detectors for Cosmic Microwave Background Polarimetry	J. Bock	JPL	FY14, 2 years	CMB
SAT2012	Demonstration of a TRL 5 Laser System for eLISA	J. Camp	GSFC	FY14, 2 years	GW
SAT2012	Phase Measurement System Development for Interferometric GW Detectors	W. Klipstein	JPL	FY14, 2 years	GW

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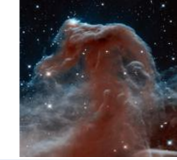
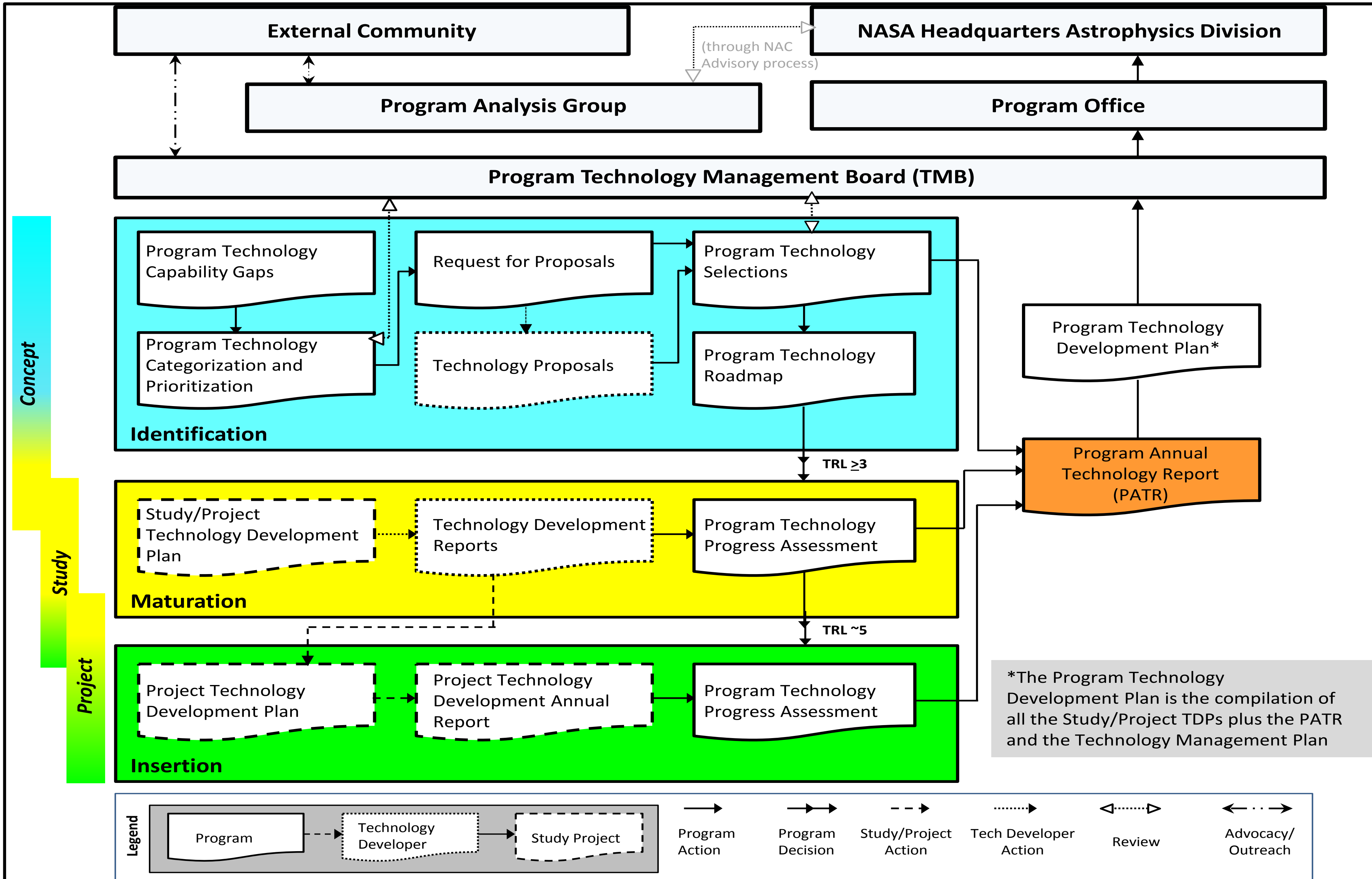
SAT Technology Management





Early SAT Successes and Future

- **TDEM** – Starlight suppression technologies competed for the down select process in the internal coronagraph for WFIRST/AFTA (2014).
- **TCOR** - NIR H4RG technology adopted as the detector to be matured for the Wide-Field Imager of WFIRST/AFTA (2014).
- **TPCOS** – TES bolometer fielded in the BICEP2 experiment, which reported the detection of CMB B polarization (2014). Also, potential X-ray technologies funded by SAT could be part of the US contribution to the upcoming L2/X-ray ESA mission (2015+).

Next SAT solicitation (proposals due on 20 March 2015) will include all three themes. Available funding for competed SAT is planned to increase toward the second half of this decade.