National Aeronautics and Space Administration

Science Mission Directorate Strategic Technology

Michael Seablom

SMD Senior Executive for Technology

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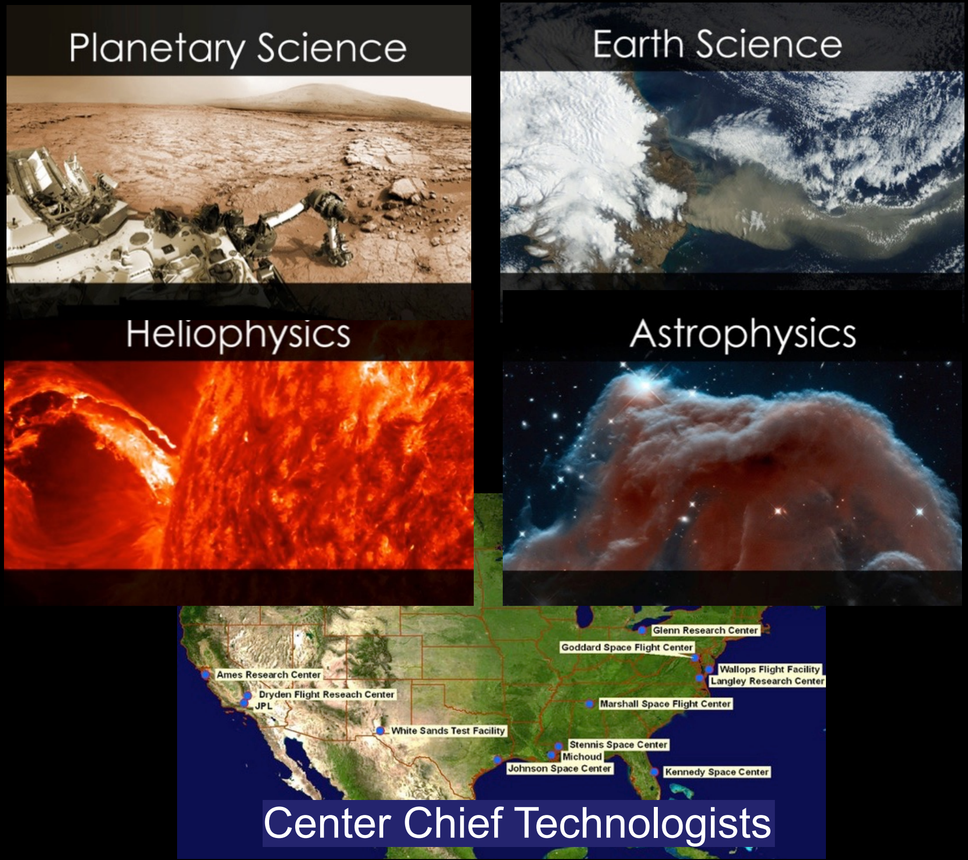
SMD Technology Federation (TechFed) - Team

Janice Buckner, HQ
Tibor Kremic, GRC
Pat Beauchamp, JPL
Len Dudzinsky, HQ

Dan Moses, HQ
Bill Stabenow, HQ



George Komar, ESTO/HQ
Azita Valania, ESTO/HQ
Mike Little, ESTO/HQ

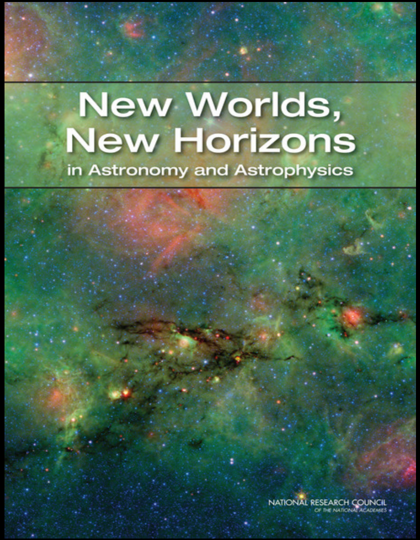
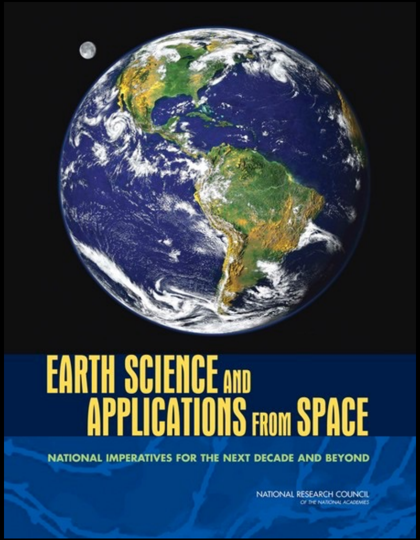
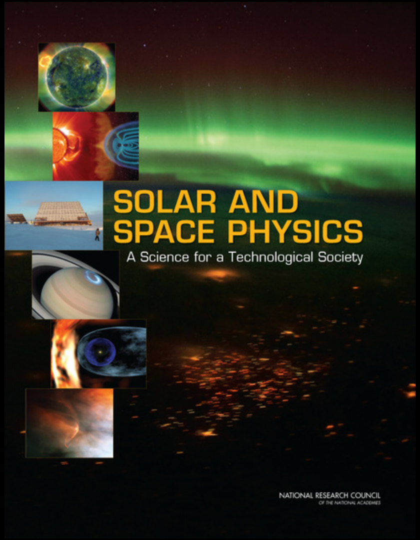
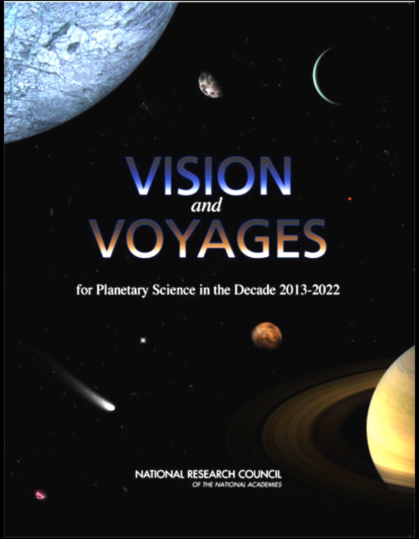
William Lightsey, HQ/MSFC
Thai Pham, GSFC

Space Technology Mission Directorate

Office of Chief Technologist

Strategically Planned Science-Driven Missions

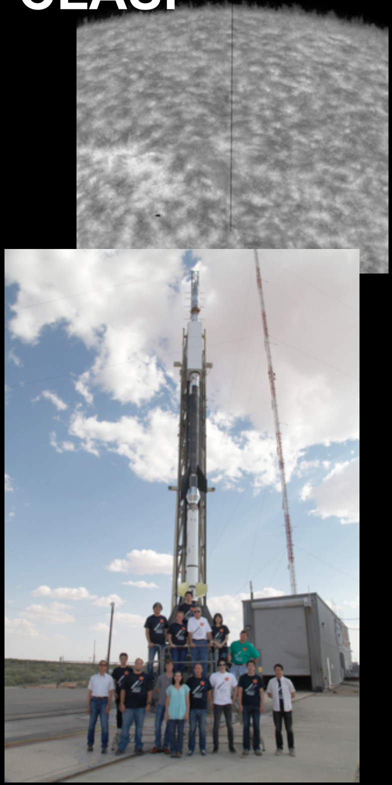
New Earth Science Decadal Survey now in planning stages

Astrophysics	Earth Science	Heliophysics	Planetary
			
2012 – 2021	2007 – 2016	2012 – 2021	2013 – 2022

Organized by the National Academies on behalf of NASA establishing USA national priorities for scientific observations, as identified by the community, within a 10-year time frame

2015 Technology Highlights - Heliophysics

CLASP

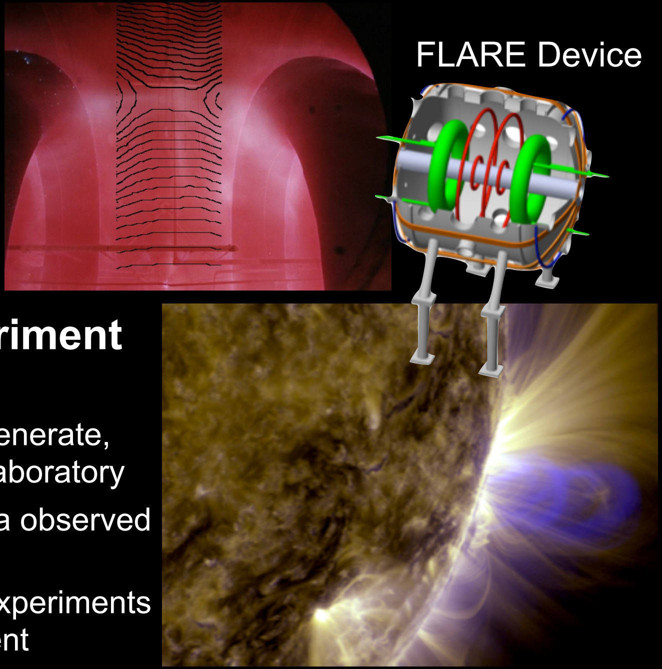


Chromospheric Lyman-Alpha Spectropolarimeter (CLASP)

- First instrument to achieve remotely-sensed magnetic field measurements of the Sun in the visible spectrum
- Technology development for low-noise CLASP camera system enabled the mission

MRX

FLARE Device

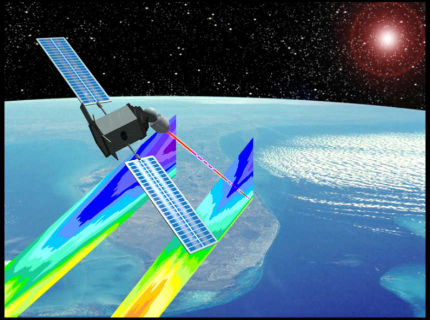


Magnetic Reconnection Experiment (MRX)

- New advancements in technology to generate, control, and diagnose plasmas in the laboratory
- Allows for reproducibility of phenomena observed in space
- Facility for Laboratory Reconnection Experiments (FLARE) device now under development

2015 Technology Highlights - Earth Science

A small satellite solution to the problem of obtaining global wind measurements?

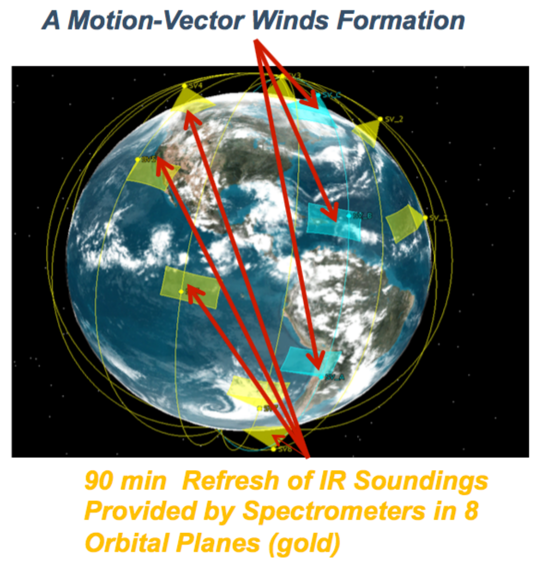


Recent Concept: Global Wind Observing Sounder (GWOS Lidar Winds)

GWOS would consist of a coherent aerosol Doppler receiver with a direct detection molecular Doppler receiver

Global 3D tropospheric wind measurements have been identified by the NRC 2007 Decadal Survey to be of "transformational" value to numerical weather prediction

NASA & NOAA have invested in wind lidar technologies for decades. Significant challenges remain: a lidar-based operational system could be years away and would be one of the most costly Earth Science missions



MISTiC Winds

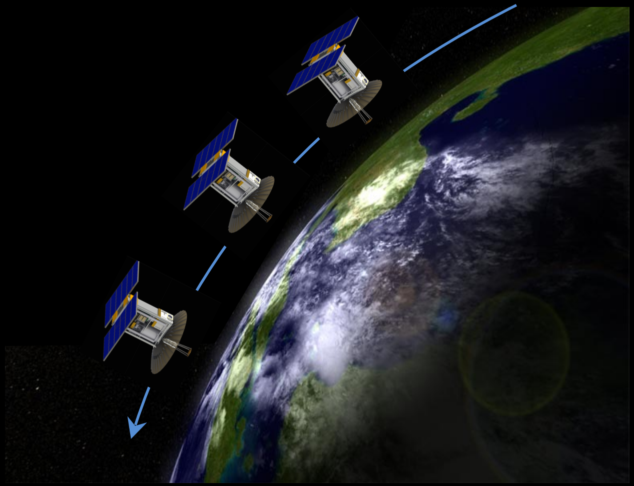
The proposed "MISTiC Winds" approach is to use a series of low-cost micro-satellites in a string of pearls constellation to provide tropospheric IR profiles of temperature and humidity at high resolution. The rapid refresh rates from the constellation would enable global, 3D winds from the troposphere

2015 Technology Highlights - Earth Science (cont'd)

Technology advances and constellations provide focused measurement options

GPM provides three-dimensional measurements of precipitation structure over 125 and 245 km swaths using a Ka-band precipitation radar (KaPR) operating at 35.5 GHz and a Ku-band precipitation radar (KuPR) operating at 13.6 GHz

Currently, the power requirements of Ku-band (narrow pulse widths) do not permit a SmallSat design, but Ka-band precipitation CubeSat radar research, such at JPL's RainCube, may enable comparable measurements more frequently using constellations

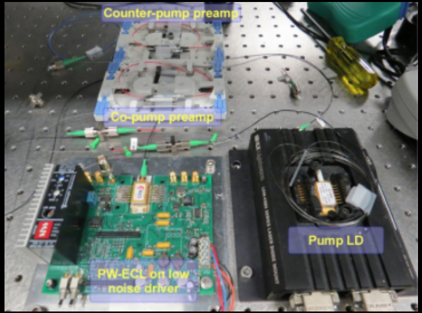


GPM (Ka/Ku-band)
11.6 meters (linear)
3,850 kg
1,950 W

Ka-band Radar
1.4 meters (linear)
336 kg
344 W
5 km spatial resolution

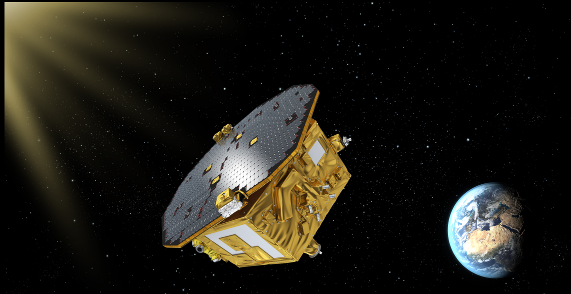
RainCube Ka-band Radar
30 centimeters (linear) 6U CubeSat
12 kg
30 W
5 km (horiz) / 250 m (range) spatial resolution

2015 Technology Highlights - Astrophysics



Demonstration of a TRL-5 Laser System for eLISA

- Supports NASA's contribution to the ESA Laser Interferometer Space Antenna (eLISA) mission
- Mission will use gravitational waves to reveal physics and astronomy associated with the merger of massive black hole systems



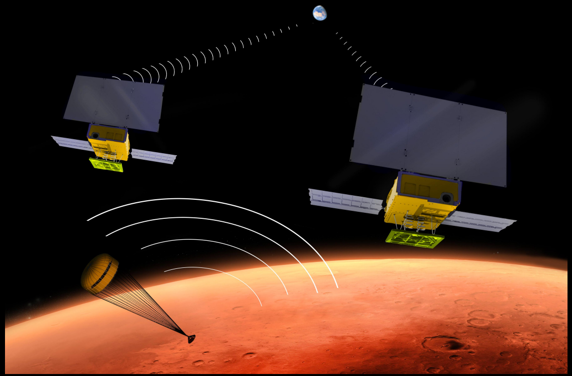
Colloid Thrusters
Component of Disturbance Reduction System

Micronewton Thruster Technology for LISA Pathfinder

- Technology demonstration mission to test new capabilities for a future gravitational wave mission
- Spacecraft must remain stable in order to detect gravity waves; NASA/JPL Disturbance Reduction System makes use of first-of-its-kind micronewton thrusters
- Software & information systems technologies provided by NASA/GSFC
- Launched on December 3, 2015; thrusters successfully tested on January 10, 2016

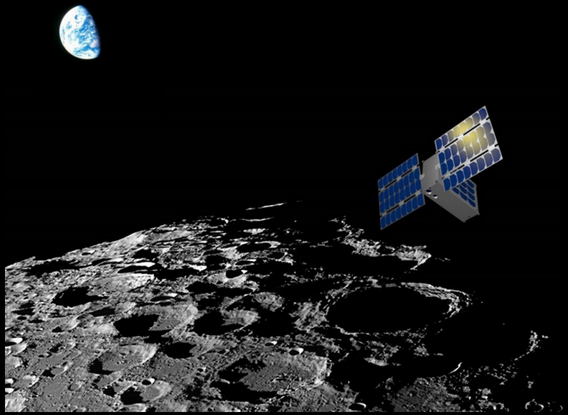
2015 Technology Highlights - Planetary Science

SIMPLEX program nurtures small satellite solutions



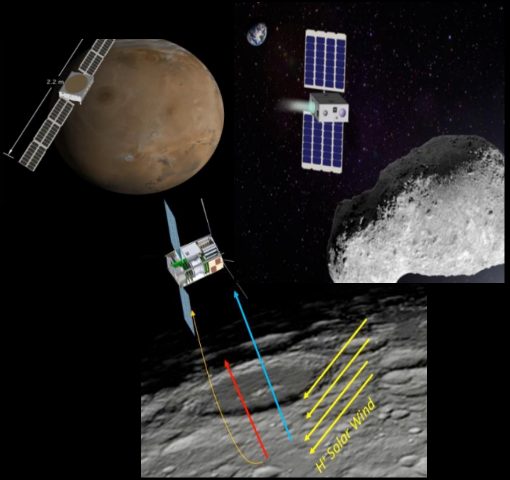
MarCO

Two 6U CubeSats, flying with the InSight mission to Mars, to act as real-time EDL telecom relays



LunaH-Map

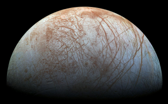
6U CubeSat that will fly on the Earth-Moon 1 (EM1) to sense the presence of hydrogen in craters and dark shadows on the Moon

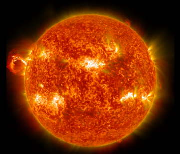


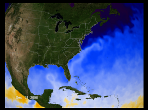
CubeSat Study Missions

Mars Micro Orbiter, Hydrogen Albedo Lunar Orbiter (HALO), Diminutive Asteroid Visitor using Ion Drive (DAVID)

Overview of SMD Technology Strategy



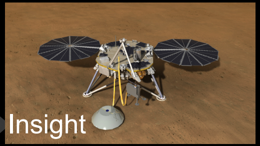


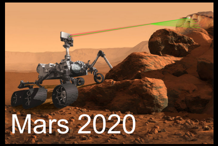


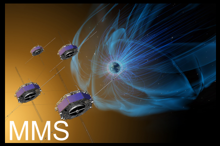
SMD Technology Program	FY16 Budget (approx)	Active Awards
Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO)	$10.5	24
Maturation of Instruments for Solar System Exploration (MatISSE)	$6.6	12
Mars Technology	$5.5	5
Europa Technology	$25.0	10
Planetary Science and Technology Through Analog Research	$5.0	11
Heliophysics - Technology and Instrument Development for Science (H-TIDeS)	$15.0	12
Instrument Incubator (IIP)	$28.3	20
Advanced Component Technology (ACT)	$6.5	17
In-Space Validation of Earth Science Technologies (InVEST)	$9.5	9
Advanced Information Systems Technology (AIST)	$14.3	34
Astrophysics Research and Analysis Program (APRA), see note below	$46.2	100
Strategic Astrophysics Technology (SAT)	$18.9	30
Nancy Grace Roman Technology Fellowships	$1.4	5
Total SMD Technology Programs	**$192.7**	**289**

APRA includes approximately 50% from balloons & sounding rocket programs

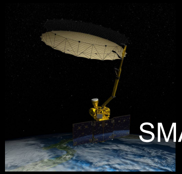
Technology programs enable competed and strategic missions





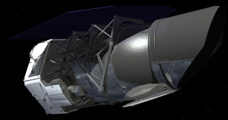


CYGNSS



SMAP

ASTRO-H



WFIRST

Heliophysics - Technology Assessment

Mission	Tech Need Date	Notional Launch Date	Tech Roadmap Elements (red=enabling, black=enhancing)	Key Technologies
Geospace Dynamics Constellation (GCD)	2019	2023	3.1.3, 8.1.1, 11.2.6, 8.1.3, 8.3.1, 11.2.6, 11.4.1, 11.4.2	Solar power, mission design analysis tools, optical components, field and particle detectors, science data systems technologies, intelligent data understanding
Interstellar Mapping and Acceleration Probe (IMAP)	2019	2022	8.3.1, 5.7.1, 5.7.2, 8.3.1, 11.2.2, 11.4.2	Wavefront control, orbital debris characterization / tracking, science data systems technologies, intelligent data understanding
Dynamical Neutral AtMosphere-Ionosphere Coupling (DYNAMIC)	2021	2024	5.2.6, 5.6.7, 5.7.1, 5.7.2, 8.1.1, 8.1.3, 11.1.2, 11.2.2, 11.2.5, 11.4.2	Antennas, reconfigurable large apertures, orbital debris characterization / tracking, ground computing, detectors and focal planes, field and particle detectors, software frameworks, intelligent data understanding
Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation (MEDICI)	2030	2035	8.1.1, 5.2.6, 5.6.7, 5.7.1, 5.7.2, 8.1.3, 11.1.2	Detectors and focal planes, antennas, reconfigurable large apertures, orbital debris characterization / tracking, field and particle detectors, software frameworks

Mission dates are notional

Earth Science - Technology Assessment

Shift toward smaller, more agile missions; New studies

Complementing Existing Programs: Increased Focus on Studies

- Observing System Simulation Experiment (OSSE) to determine anticipated performance of IR wind technique (under discussion / IIP, AIST with Earth Science Research and Analysis)
- Joint with STMD: Study to examine the use of sensor webs for next-generation weather architecture (under discussion / AIST with NOAA/STAR)
- Big Data Analytics (active)
- Small satellite capabilities for Earth Science

Technology Priorities		
ACT	**IIP**	**AIST**
Low-SWAP laser transmitters	Lasers	Re-configurable ground systems
Optical detectors	Radars	Control systems for small satellites
Controllers for improved pointing accuracy	Passive Optical Instruments	Data mining / visualization / exploration
Depolarizers	Passive Microwave	Specialized processors
Dual frequency scanning antennas	Reduce SWaP (miniaturization)	Big Data Analytics for Earth Science
Solid state power amplifiers		Quantum Computing Algorithms
Miniaturized RF electronics		Advanced techniques for EOSDIS

Small Spacecraft for Earth Science

Classifying potential instrument/measurement options from SmallSat Study

Mission	SmallSat Instrument	SmallSat Capable	Architecture	Key Technologies
CloudSat	Cloud Profiling Radar	Potentially Yes: ESPA+	Constellation	2m deployable antenna, high power system
GACM	UV/VIS/SWIR Spectrometer, microwave limb sounder	Yes: 12U to ESPA	Constellation	Differential absorption LIDAR
GEO-CAPE	UV/VIS/NIR Wide Area and event imaging spectrometer, TIR radiometer	Yes: Hosted Payload, Propulsive ESPA	Constellation	UV-NIR wide field imaging spectrometer
GPM Core	3D dual precipitation radar (Ka/Ku) with multichannel microwave imager	Yes: Ka-band/microwave No: Ku-band radar	Constellation	Ku-band narrow pulse precipitation radar
HyspIRI	Visible-shortwave infrared spectrometer and thermal infrared imager	Yes: Pegasus Mini Satellites	Instruments on separate platforms	Compact Dyson spectrometer
NISAR	Circularly Polarized SAR (CP-SAR) at L-band	Probably Not: ESPA	Repeat Pass or Constellation	2m x 5m deployable antenna
SMAP	Wide swath shared aperture radar/radiometer	No	N/A	Wide swath shared aperture measurement
SWOT	Long baseline Ka-band radar	Probably Not: ESPA+	Repeat Pass or Constellation	Precision formation flying, on-board interferometry

50+ missions under study where SmallSat performance tradeoffs exists compared to original DS missions

Decadal-Class Science Measurement Requirements

Comparing measurement drivers and alternative approaches

Mission	Driving Requirement	Alternative Architecture	Enabling Technology
QuickScat	Ocean surface wind speed and direction Scatterometer: 1,800 km swath, wind speed 3-20 m/s and 25 km wind vector resolution	GPS reflectometry constellation architecture for frequent revisits (e.g. CYGNSS)	Delay Doppler mapping instruments (GPS receivers)
HyspIRI	Surface composition & ecosystem health VSWIR: 60m spatial resolution, 19-day revisit TIR: 60m spatial resolution, 5-day revisit	Separate spacecraft designed to SmallSat Pegasus configuration (e.g. Dyson-VSWIR)	Compact Dyson imaging spectrometer design
GPM	3D precipitation structure Ka-band (35.5 GHz) and Ku-band (13.6 GHz) precipitation radars at 125 km and 245 km swaths	Ka-band constellation alternative measurement approach (e.g. RainCube)	Ka-band deployable antenna and pulse compression method
PATH	All-weather temp/humidity soundings Spectrometric observations of microwave emission in 50-70, 118, 183 GHz lines	Radiometer and/or GPSRO constellation architecture (e.g. Mistic Winds / MiRaTA)	Compact MWIR design, radiometers, and GPS receivers
3D Winds	3D Tropospheric winds 2-micron and ultraviolet Doppler wind lidar	No immediate alternative	Laser SWaP and duty cycle capabilities must advance

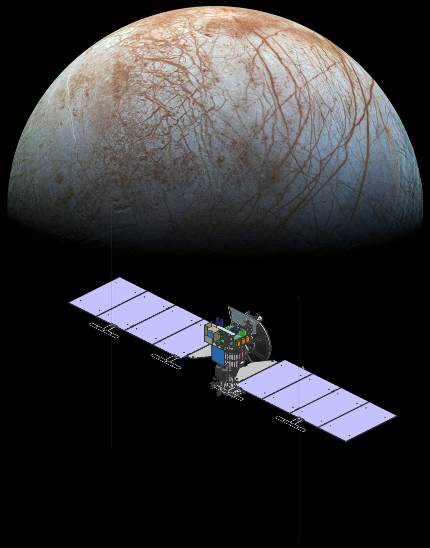
Alternative approaches either provide an equivalent measurement, no clear alternative, or a reduced scope measurement that may satisfy specific requirements

Astrophysics - Technology Assessment

Mission	Tech Need Date	Notional Launch Date	Tech Roadmap Elements (red=enabling, black=enhancing)	Key Enabling Technologies
WFIRST	2018	2025	8.1.1, 8.1.3, 10.1.3	Detector arrays, coronagraphs, adaptive optics, wavefront sensing
Exoplanet / Large Telescopes	2030	2035	8.1.3, 8.2.3, 5.2.6, 5.6.7, 5.7.1, 5.7.2, 8.1.1, 8.2.1,11.4.2, 12.2.1, 12.3.1	Star shades, adaptive optics, vibration suppression, wavefront sensing and control
LUVOIR	2030	2035	2.2.1, 8.1.1, 8.1.3, 8.2.1, 8.2.3, 10.4.3, 12.2.1, 12.3.1, 12.4.3	Telescope deployment and alignment systems, coatings, detectors, starlight suppression systems
X-Ray Surveyor	2030	2035	8.1.1, 8.2.1, 12.2.1, 12.2.5, 12.4.3, 5.2.6, 5.6.7, 5.7.1, 8.1.6, 11.3.5, 12.2.5, 12.4.3, 14.1.2	Mirrors, coatings, assembly and alignment, metrology, calibration, and verification, microcalorimeter arrays,array readout, gratings
Far Infrared Surveyor	2035	2040	14.1.2, 5.2.6, 5.6.7, 5.7.1, 5.7.2, 8.1.6, 10.4.3, 11.4.2, 14.1.1	Telescopes, interferometry, detectors, sub-Kelvin focal plane coolers,wide-field spectrometers
Cosmic Microwave Background Surveyor	2035	2040	8.1.1, 8.1.6, 5.2.6, 5.6.7, 5.7.1, 5.7.2, 10.4.3, 11.1.2	Large arrays of sensitive millimeter wavelength detectors
Gravitational Wave Surveyor	2040	2045	8.1.3, 8.1.5, 5.2.6, 5.6.7, 5.7.1, 5.7.2, 8.1.3, 11.1.2	Thrusters, frequency-stabilized lasers, high rigidity telescopes and optical benches, precision gravitational reference sensors, high-cadence phase meters

Planetary Science - Technology Trends

Immediate need - augmentation of Europa mission(s)



Early Mission Technologies

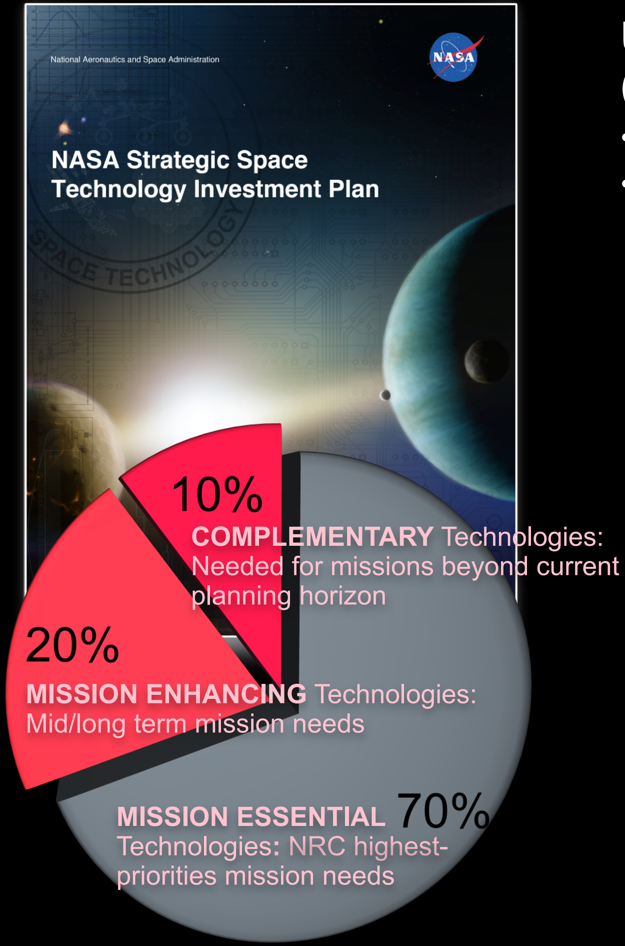
- Entry, Descent, Landing
- Landers - Short Duration
- Battery Storage
- Passive Thermal Control
- Radiation Hardened Electronics
- Cold Temperature Mechanisms
- Autonomy
- Guidance, Navigation, and Control
- In Situ Instruments
- Planetary Protection

Advanced Mission Technologies

- Entry, Descent, Landing
- Landers - Long Duration
- Battery Storage
- Passive Thermal Control
- Radiation Hardened Electronics
- Cold Temperature Mechanisms
- Autonomy
- Guidance, Navigation, and Control
- In Situ Instruments
- Planetary Protection
- Mobile Surface Platforms
- Radioisotope Power
- Cold Temperature Electronics
- Communications
- In Situ Surface - Suborbital Platforms

Planetary Science Technology Working Group assessing currently-identified technology gaps and will make recommendations for near-term investments

Programmatic Trends



Updates to the NASA Strategic Technology Investment Plan (STIP)

- Determining appropriate balance between investment priorities
- Identifying potential areas for divesting (for re-investing in higher priority areas)

Expanding Technology Demonstrations

- Ongoing discussions with Heliophysics, Astrophysics, and Earth Science to determine if technology demonstrations can be included in Explorers, New Frontiers, Earth Venture
- "Technology Pipeline" nurtured by STMD and SMD technology programs with a longer-term focus on technology demonstration
- Goal is to address NAC comments that NASA is not properly leveraging new technologies in its missions, particularly for small- and medium-class

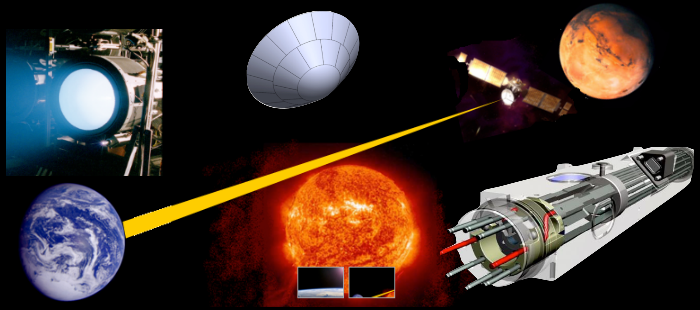
Transition from a Static to Dynamic Technology Strategy?

- A fundamental shift from static, stovepipe programs to dynamic, goal-based technology investments
- Process defined for negotiating trades between competing objectives rather than a sequence of planning submissions
- Entirely goal-oriented

Infusion of New Technologies into Science Missions

Planetary Science Division Assessing Lessons Learned from Discovery ’14 Tech Infusion

- Technology infusions promoted via GFEs, evaluation incentives, and commercialization options
- GFEs: NEXT-C ion propulsion system, Deep Space Optical Comm, Lightweight Radioisotope Heater Units ($5M)
- Incentives: Deep Space Atomic Clock, 3D-woven thermal protection system ($10M)
- Good response: 18 of 27 proposals included some technology demonstration or infusion option
- Tech Demo requirements need to be more detailed in future AOs
- Interfaces need to be better defined



Tech Infusion for Discovery ’14 was a partnership between SMD and the Game-Changing and Technology Demonstration Programs of STMD

Proposers were also allowed to include their own demonstrations without additional penalties for inherent technical risks

Goal: Determine if this technology infusion model can be expanded to other Divisions

Current Technology Value Chain for Astrophysics Explorers

Strategic Astrophysics Technology (SAT)

Physics of the Cosmos | *Cosmic Origins* | *Explanet Exploration*

TRL 3-6; ~$17M per year

Astrophysics Research & Analysis (APRA)

TRL 1-5; ~$46M per year

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Suborbital Validation Platforms

Sounding Rockets, Balloons, Cubesats

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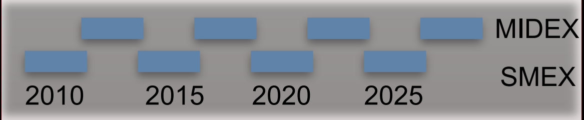


Astrophysics Explorers

Competed Missions

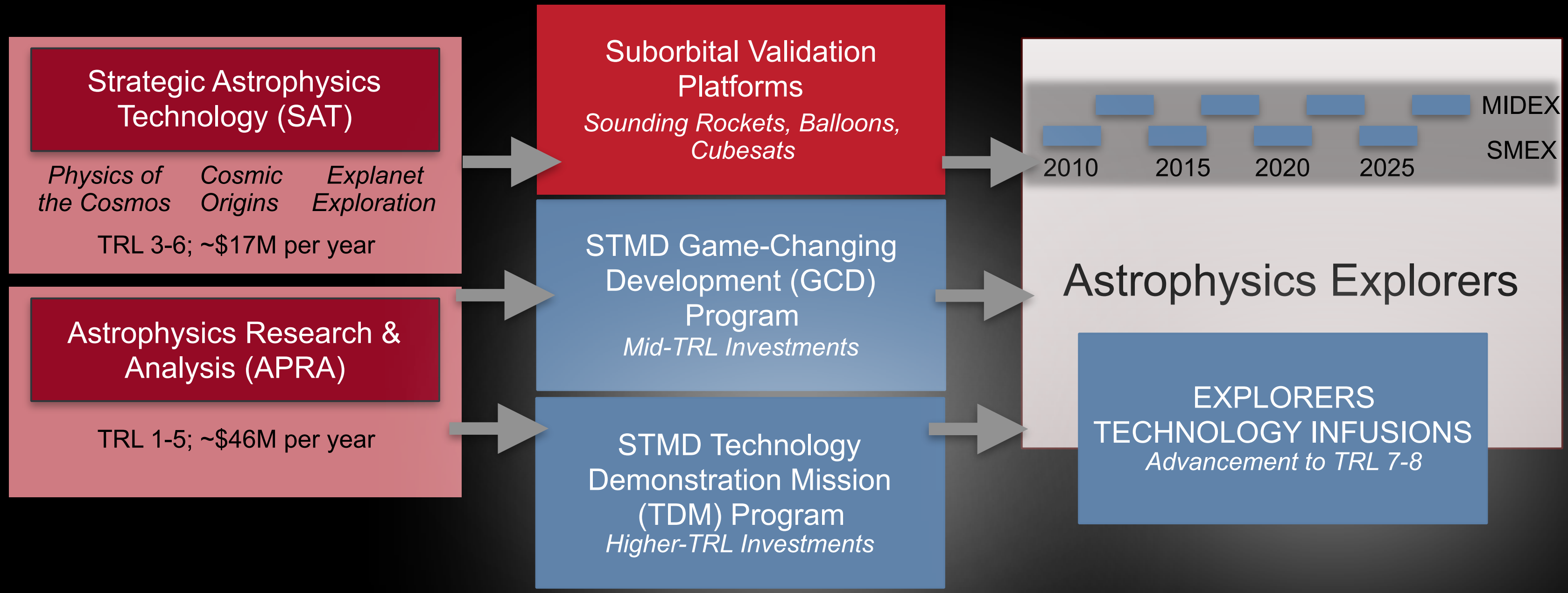
SMEX: ~$200M

MIDEX: ~$400M

Astrophysics SAT, APRA programs are effective incubators of technology

- SAT focuses on requirements for Astrophysics Decadal Survey missions
- APRA + SAT investments provide good coverage for technology maturation for competed and strategic missions
- To date, Explorers has not been used for technology demonstrations / validations

Proposed Technology Value Chain for Astrophysics Explorers



New strategy includes:

- Enhanced value chain for technology maturation via GCD and TDM programs: annual selections of SAT and APRA projects for targeted infusion
- Explorers expanded to include technology demonstrations

Current Technology Value Chain for Heliophysics Explorers

Heliophysics Instrument Technology Development for Science (H-TIDS)

TRL 1-5; ~$15M per year

→

Suborbital Validation Platforms

Sounding Rockets, Balloons, Cubesats

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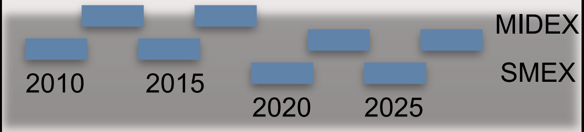


Heliophysics Explorers

Competed Missions

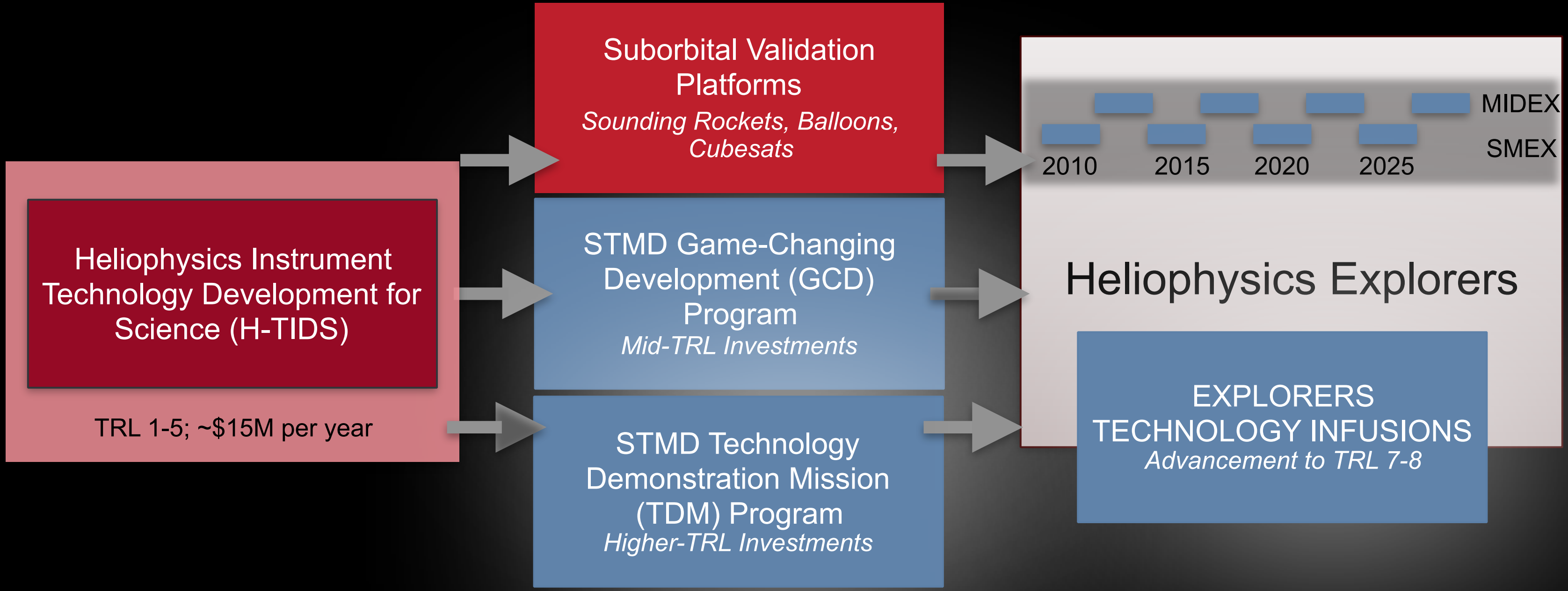
SMEX: ~$180M

MIDEX: ~$300M

HiTIDS: Currently the only technology program in Heliophysics

- Program provides modest funding for maturing technologies for strategic and competed missions
- To date, Explorers has not been used for technology demonstrations / validations

Proposed Technology Value Chain for Heliophysics Explorers



New strategy includes:

- Similar to Astrophysics, enhanced value chain for technology maturation via GCD and TDM programs: annual selections of H-TIDS projects for targeted infusion
- Explorers expanded to include technology demonstrations