NASA Astrophysics Technology Needs

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AGENDA

Office of Chief Technologist (OCT) Technology Area Roadmap

Science Instrument, Observatory and Sensor Systems TA

- Needs Assessment
- Technology Area Breakdown Structure (TABS)
- Technology Development Roadmaps
- Top Challenges
- Interdependencies with other TAs and Government Agencies
- Budget Recommendations

Conclusions

NASA Office of Chief Technologist

Aero-Space Technology Area Roadmap (A-STAR)

Aero-Space Technology Area Roadmap (A-STAR)

July 2010, NASA Office of Chief Technologist (OCT) initiated an activity to create and maintain a NASA integrated roadmap for 15 key technology areas which recommend an overall technology investment strategy and prioritize NASA's technology programs to meet NASA's strategic goals.

Initial reports were presented to the National Research Council who are currently collecting public input and preparing reviews of each Roadmap.

Roadmaps will be updated annually and externally reviewed every 4 years consistent with the Agency's Strategic Plans.

Technology Assessment Areas

TA1: Launch Propulsion Systems
TA2: In-Space Propulsion Systems
TA3: Space Power and Energy Storage Systems
TA4: Robotics, Tele-robotics, and Autonomous Systems
TA5: Communication and Navigation Systems
TA6: Human Health, Life Support and Habitation Systems
TA7: Human Exploration Destination Systems
TA8: Scientific Instruments, Observatories, and Sensor Systems
TA9: Entry, Descent, and Landing Systems
TA10: Nanotechnology
TA11: Modeling, Simulation, Information Technology, and Processing
TA12: Materials, Structural & Mechanical Systems, and Manufacturing
TA13: Ground and Launch Systems Processing
TA14: Thermal Management Systems
TA15: Aeronautics

Goals and Benefits

Develop clear NASA technology portfolio recommendations

- Prioritize current needs
- Define development plans
- Identify alternative paths
- Reveal interrelationships of between various technologies

Transparency in government technology investments

- Ensure needs of all NASA Mission Directorates are included

Credibility for planned NASA technology programs

- Coordinate with other Government agencies
- Broad-based input from non-government parties

Charge to TA Teams

Review, document, and organize the existing roadmaps and technology portfolios.

Collect input from key Center subject matter experts, program offices and Mission Directorates.

Take into account:

- US aeronautics and space policy;
- NASA Mission Directorate strategic goals and plans;
- Existing Design Reference Missions, architectures and timelines; and
- Past NASA technology and capability roadmaps.

Recommend 10-yr Budget to Mature Technology to TRL6

Technology Assessment Content

- Define a breakdown structure that organizes and identifies the TA
- Identify and organize all systems/technologies involved in the TA using a 20-year horizon
- Describe the state-of-the-art (SOA) for each system
- Identify the various paths to achieve performance goals
- Identify NASA planned level of investment
- Assess gaps and overlaps across planned activities
- Identify alternate technology pathways
- Identify key challenges required to achieve goals

Technology Assessment #8:

Science Instruments, Observatories and Sensor Systems (SIOSS)

TA8 Roadmap Team

Rich Barney (GSFC), Division Chief, Instrument Systems and Technology Division.

Co-chaired 2005 NASA Science Instruments and Sensors Capability Roadmap.

Phil Stahl (MSFC), Senior Optical Physicists

Optical Components Technical Lead for James Webb Space Telescope;

Mirror Technology Days in the Government;

Advanced Optical Systems SBIR Subtopic Manager;

2005 Advanced Observatories and Telescopes Capability Roadmap.

Upendra Singh (LaRC), Chief Technologist, Engineering Directorate.

Principal Investigator for NASA Laser Risk Reduction Program (2002-2010)

Dan Mccleese (JPL), Chief Scientist

Principal Investigator of Mars Climate Sounder instrument on Mars Reconnaissance Orbiter.

Jill Bauman (ARC), Associate Director of Science for Mission Concepts.

Lee Feinberg (GSFC), Chief Large Optics System Engineer

JWST OTE Manager.

Co-chaired 2005Advanced Telescopes and Observatories Capability Roadmap.

SIOSS

SIOSS roadmap addresses technology needs to achieve NASA's highest priority objectives – not only for the Science Mission Directorate (SMD), but for all of NASA.

SIOSS Team employed a multi-step process.

- Performed an SMD needs assessment;
- Consolidated the identified technology needs into broad categories and organized them into a Technology Area Breakdown Structure (TABS);
- Generated technology development roadmaps for each TABS element;
- Investigated interdependencies with other TA Areas as well as the needs of Other Government Agencies.

SMD Needs Assessment

First step was to review governing documents (such as Decadal Surveys, roadmaps, and science plans) for each Science Mission Directorate (SMD) divisions: Astrophysics, Earth Science, Heliophysics, and Planetary Science:

2010 Science Plan, NASA Science Mission Directorate, 2010

Agency Mission Planning Manifest, 2010

New Worlds, New Horizons in Astronomy and Astrophysics, NRC Decadal Survey, 2010

Panel Reports: — New Worlds, New Horizons in Astronomy and Astrophysics, NRC Decadal Survey, 2010

Heliophysics, The Solar and Space Physics of a New ERA, Heliophysics Roadmap Team Report to the NASA Advisory Council, 2009

Earth Science and Applications from Space, NRC Decadal Survey, 2007

New Frontiers in the Solar Systems, NRC Planetary Decadal Survey, 2003

The Sun to the Earth — and Beyond, NRC Heliophysics Decadal Survey, 2003

Advanced Telescopes and Observatories, APIO, 2005

Science Instruments and Sensors Capability, APIO, 2005

Astrophysics Technology Needs

National Academy 2010 Decadal Report recommended missions and technology-development programs, (with need date):

Wide Field Infrared Survey Telescope (WFIRST), 2018

Explorer Program, 2019/2023

Laser Interferometer Space Antenna (LISA), 2024

International X-ray Observatory (IXO), mid/late 2020s

New Worlds Technology Development Program, mid/late 2020s

Epoch of Inflation Technology Development Program, mid/late 2020s

U.S. Contribution to the JAXA-ESA SPICA Mission, 2017

UV-Optical Space Capability Technology Development Program, mid/late 2020s

TRL3-to-5 Intermediate Technology Development Program

All can be enhanced or enabled by technology development to reduce cost, schedule, and performance risks.

SMD Needs Assessment

Detailed listings of technology needs for each SMD division were tabulated which enable either:

- planned SMD missions ('pull technology') or
- emerging measurement techniques necessary for new scientific discovery ('push technology').

These lists were then reviewed and refined by individual mission and technology-development stakeholders.

Table 2.2.1.1 – 1 Summary of Astrophysics Technology Needs

Mission	Technology	Metric	State of Art	Need	Start	TRL6
WFIRST	NIR detectors	Pixel array Pixel size	2k x 2k 18 μm	4k x 4k 10 μm	2012	2014
UVOTP Push	Detector arrays: Low noise	Pixel QE UV QE Visible Rad Hard	2k x 2k	4k x 4k > 0.5 90-300 nm > 0.8 300-900 nm 50 to 200 kRad	2012	2020
NWTP Push	Photon counting arrays	Pixel array visible Visible QE Pixel array NIR	512 x 512 80% 450-750 nm 128 x 128	1k x 1k >80% 450-900 nm 256 x 256	2011	2020
SPICA ITP Push	Far-IR detector arrays	Sens. (NEP W/√Hz) Wavelength Pixels	1e-18 > 250μm 256	3e-20 35-430μm 1k x 1k	2011	2015 2020
IXO Push	X-ray detectors	Pixel array Noise QE Frame rate	 10-15 e^- RMS 100 kHz@2e^-	40 x 40 TES 2-4 e^- RMS >0.7 0.3-8 keV 0.5 - 1 MHz@2e^-	2011	2015
WFIRST IXO	Detector ASIC	Speed @ low noise Rad tolerance	100 kHz 14 krad	0.5 - 1 MHz 55 krad	2011	2013
NWTP	Visible Starlight suppression: coronagraph or occulter	Contrast Contrast stability Passband Inner Working Angle	> 1 x 10^{-9} --- 10%, 760-840 nm 4 λ/D	< 1 x 10^{-10} 1 x 10^{-11}/image 20%, at *V*, *I*, and *R* 2λ/D – 3λ/D	2011 2011	2016 2020
NWTP	Mid-IR Starlight suppres: interferometer	Contrast Passband mid-IR	1.65 x 10^{-5}, laser 30% at 10 μm	< 1 x 10^{-7}, broadband > 50% 8μm	2011 2011	2016 2020
NWTP UVOTP	Active WFSC; Deformable Mirrors	Sensing Control (Actuators)	λ/10,000 rms 32 x 32	< λ/10,000 rms 128 x 128	2011	2020
IXO	XGS CAT grating	Facet size; Throughput	3x3 mm; 5%	60x60mm; 45%	2010	2014
Various	Filters & coatings	Reflect/transmit; temp			2011	2020
Various	Spectroscopy	Spectral range/resolve			2011	2020
SPICA IXO	Continuous sub-K refrigerator	Heat lift Duty cycle	< 1 μW 90 %	> 1 μW 100 %	2011	2015
IXO Push	Large X-ray mirror systems	Effective Area HPD Resolution Areal Density; Active	0.3 m2 15 arcsec 10 kg/m2; no	>3 m2 (50 m2) <5 arcsec (<1 as) 1 kg/m2; yes	2011	2020 (30)
NWTP UVOTP Push	Large UVOIR mirror systems	Aperture diameter Figure Stability Reflectivity kg/m2 $/m2	2.4 m < 10 nm rms --- >60%, 120-900 nm 30 kg/m2 $12M/m2	3 to 8 m (15 to 30 m) <10 nm rms >9,000 min >60%, 90-1100 nm Depends on LV <$1M/m2	2011	2020 (30)
WFIRST	Passive stable structure	Thermal stability	Chandra	WFOV PSF Stable	2011	2014
NWTP	Large structure: occulter	Dia; Petal Edge Tol	Not demonstrated	30-80 m; <0.1mm rms	2011	2016
NWTP UVOTP Push	Large, stable telescope structures (Passive or active)	Aperture diameter Thermal/dynamic WFE Line-of-sight jitter kg/m2 $/m2	6.5 m 60 nm rms 1.6 mas 40 kg/m2 $4 M/m2	8 m (15 to 30 m) < 0.1 nm rms 1 mas <20 (or 400) kg/m2 <$2 M/m2	2011	2020 (30)
LISA NWTP	Drag-Free Flying Occulter Flying	Residual accel Range Lateral alignment	3x10^{-14} m/s^2/√Hz	3x10^{-15} m/s^2/√Hz 10,000 to 80,000 km ±0.7 m wrt LOS	2011	2016
NWTP Push	Formation flying: Sparse & Interferometer	Position/pointing #; Separation	5cm/6.7arcmin 2; 2; 2 m	 5; 15–400-m	2011	2020
LISA Push	Gravity wave sensor Atomic interferometer	Spacetime Strain Bandpass	N/A	1x10^{-21}/√Hz, 0.1- 100mHZ	2013	2019
Various	Communication	Bits per sec		Terra bps		2014

Astrophysics Technology Needs

Astrophysics requires advancements in 5 SIOSS areas:

- Detectors and electronics for X-ray and UV/optical/infrared (UVOIR);
- Optical components and systems for starlight suppression, wavefront control, and enhanced UVOIR performance;
- Low-power sub-10K cryo-coolers;
- Large X-ray and UVOIR mirror systems (structures); and
- Multi-spacecraft formation flying, navigation, and control.

Additionally, Astrophysics missions require other technologies:

- Affordable volume and mass capacities of launch vehicles to enable large-aperture observatories and mid-capacity missions;
- Terabit communication; and
- Micro-Newton thrusters for precision pointing & formation-flying control

Technology Area Breakdown Structure (TABS)

Technology needs for each SMD area were deconstructed into broad categories.

For example, many missions require new or improved detectors.

These broad categories were condensed into 3 groups:

Remote Sensing Instruments/Sensors,

Observatories, and

In-situ Instruments/Sensors.

and organized into a 4-level TABS.

TA8: Technology Area Breakdown Structure

8.0 Science Instruments, Observatories & Sensor Systems

8.1 Remote Sensing Instruments/Sensors

(8.1.1) Detectors and Focal Planes

8.1.1.1 Large Format Arrays
8.1.1.2 Spectral Detectors
8.1.1.3 Polarization Sensitive Det.
8.1.1.4 Photon-Counting Det.
8.1.1.5 Radiation-Hardened Det.
8.1.1.6 Sub-Kelvin High-Sensitivity Det.

(8.1.2) Electronics

8.1.2.1 Radiation Hardened
8.1.2.2 Low Noise
8.1.2.3 High Speed

(8.1.3) Optical Components

8.1.3.1 Starlight Suppression
8.1.3.2 Active Wavefront control
8.1.3.3 Optical Components
8.1.3.4 Advanced Spectrometers/Instruments

(8.1.4) Microwave & Radio Transmitters & Receivers

8.1.4.1 Integrated Radar T/R Modules
8.1.4.2 Integrated Radiometer Receivers

(8.1.5) Lasers

8.1.5.1 Pulsed Lasers
8.1.5.2 CW Lasers

(8.1.6) Cryogenic/Thermal

8.1.6.14-20K Cryo-Coolers for Space
8.1.6.2 Sub-Kelvin Coolers

8.2 Observatories

(8.2.1) Large Mirror Systems

8.2.1.1 Grazing Incidence
8.2.1.2 Normal Incidence

(8.2.2) Large Structures & Antenna

8.2.2.1 Passive Ultra-Stable Structures
8.2.2.2 Deployable/Assembled Tel. Support Structure and Antenna
8.2.2.3 Active Control

(8.2.3) Distributed Apertures

8.2.3.1 Formation Flying

8.3 In-Situ Instruments/Sensors

(8.3.1) Particles

8.3.1.1 Energetic Particle Det. (>30keV-NMeV)
8.3.1.2 Plasma Det. (<1eV-30keV)
8.3.1.3 Magnetometers (DC & AC)

(8.3.2) Fields & Waves

8.3.2.1 EM Field Sensors
8.3.2.2 Gravity-Wave Sensors

(8.3.3) In-Situ

8.3.4.1 Sample Handling, Preparation, and Containment
8.3.4.2 Chemical and Mineral Assessment
8.3.4.3 Organic Assessment
8.3.4.4 Biological Detection & Characterization
8.3.4.5 Planetary Protection

Technology Area Breakdown Structure (TABS)

Remote Sensing Instruments/Sensors:

convert electromagnetic radiation (photons or waves) into science data or generate electromagnetic radiation (photons or waves);

typically require an observatory;

may be stand-alone sharing a common spacecraft bus

Observatory: collect, concentrate, and/or transmit photons.

In-situ Instruments/Sensors create science data from:

fields or waves (AC/DC electromagnetic, gravity, acoustic, seismic, etc);

particles (charged, neutral, dust, etc.); or

physical samples (chemical, biological, etc.).

Technology Development Roadmaps

Development Roadmaps were developed for each SMD Division.

Roadmaps use TABS structure with direct traceability to identified mission needs for each Division.

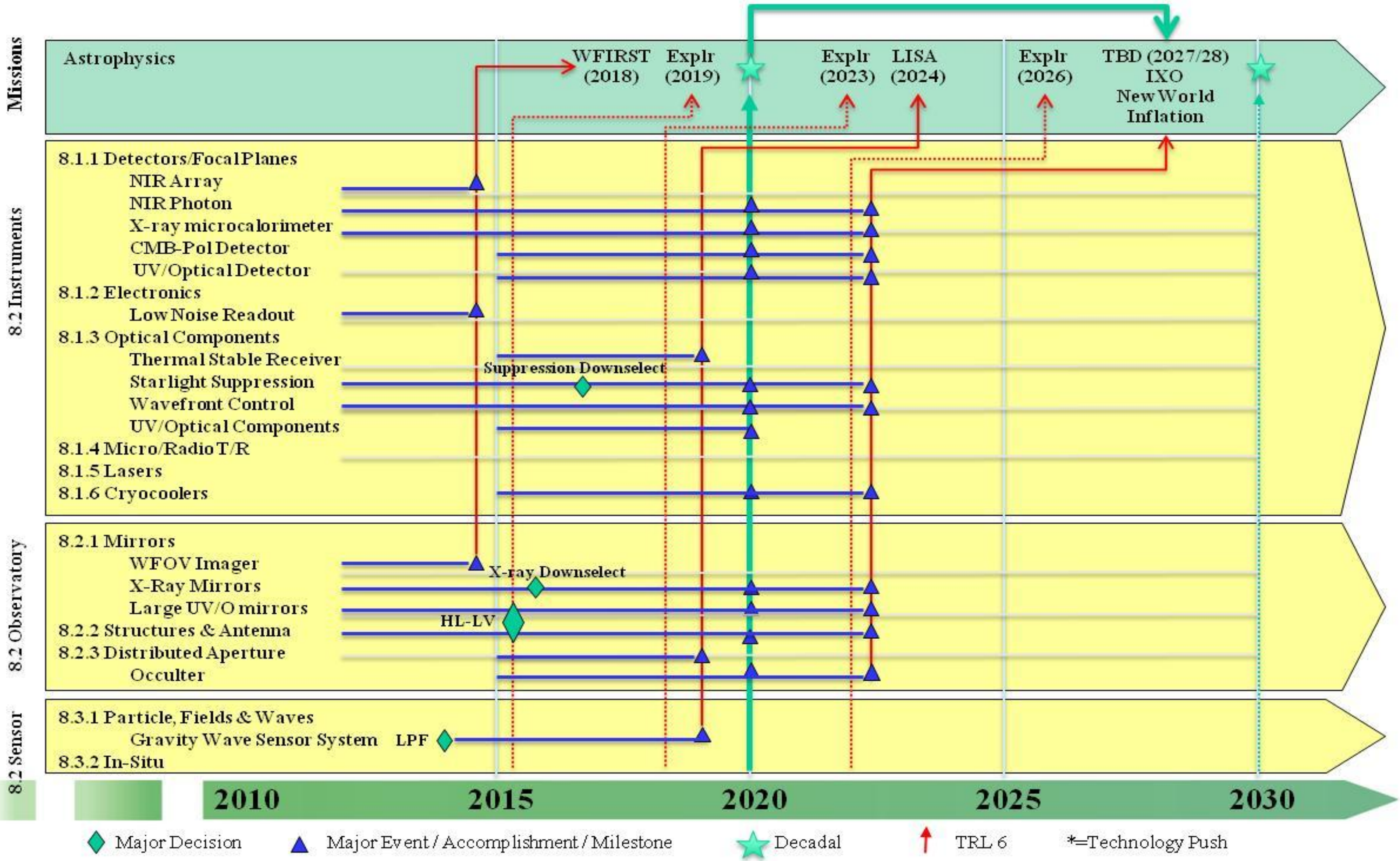
Each technology need has specific maturity milestones (TRL-6).

Some technology needs have alternative pathway decision points.

Roadmaps explicitly includes 2020 & 2030 Decadal Reviews

Explorer missions do not have explicit technology needs.

Astrophysics Technology Development Roadmap



Top Technical Challenges

Top Challenges list was condensed from SMD assessments.

For near- & mid-term investments, goal is to advance state of art for each Challenge by 2 to 10X.

Long-term goal is to develop revolutionary capabilities

Investment must be balanced between short- and long-term to account for differences in maturity rates.

Top Technical Categories are not in any priority order; rather the list is organized by general need within selected timeframes.

Actual funding decisions will be determined by open competition and peer review. Competition is the fastest, most economical way to advance the state of the art.

Top Technical Challenges

Present to 2016
In-situ Sensors for Mars Sample Returns and In-Situ Analysis Miniaturization, Sample gathering, caching, handling, and analysis In situ drilling and instrumentation
Low-Cost, Large-Aperture Precision Mirrors UV and Optical Lightweight mirrors, 5 to 10 nm rms, <$2M/m2, <30kg/m2 X-ray: <5 arc second resolution, < $0.1M/m2 (surface normal space), <3 kg/m2
High Efficiency Lasers Higher Power, High Efficiency, Higher Rep Rate, Longer Life, Multiple Wavelengths
Advanced Microwave Components and Systems Active and Passive Systems; Improved frequency bands, polarization, scanning range, bandwidth, phase stability, power
High Efficiency Coolers Low Vibration, Low Cost, Low Mass; Continuous Sub-Kelvin cooling (100% duty cycle), 70K cryostat
In-situ Particle, Field and Wave Sensors Miniaturization, Improved performance capabilities; Gravity Wave Sensor: 5µcy/√Hz, 1-100mHz
Large Focal Plane Arrays All Wavelengths (FUV, UV, Visible, NIR, IR, Far-IR), Higher QE, Lower Noise; Sensors and Packaging (4Kx4K and beyond)
Radiation hardened Instrument Components Electronics, detectors, miniaturized instruments.
2017 to 2022 (Requires Funding Now)
High Contrast Exoplanet Technologies High Contrast Nulling and Coronagraphic Algorithms and Components (1x10^-10, broadband); Occulters (30 to 100 meters, < 0.1 mm rms)
Ultra Stable Large Aperture UV/O Telescopes > 50 m2 aperture, < 10 nm rms surface, < 1 mas pointing, < 15 nm rms stability, < $2M/m2
Atomic Interferometers Order of magnitude improvement in gravity sensing sensitivity and bandwidths Science and Navigation applications
2023 and Beyond
Advanced spatial interferometric imaging including Wide field interferometric imaging Advanced nulling
Many Spacecraft in Formations Alignment, Positioning, Pointing, Number of Spacecraft, Separation

Public Input

The National Research Council received 63 SIOSS inputs.

67% (42/63)	8.1 Remote Sensing Instruments/Sensors
14% (9/63)	8.2 Observatories
19% (12/63)	8.3 In-Situ Instruments/Sensors

Most were corrections, clarifications & amplifications of content already in the report.

Others pointed out technologies which the assessment team had missed – such as needs for Gamma Ray science.

Many were made ‘collective’ or ‘consensus’ inputs on behalf of individual science communities.

Public Input

8.1 Remote Sensing Instruments/Sensors

14 inputs regarding Detectors and Focal Planes

14 inputs regarding Electronics

9 inputs regarding Optical Components

3 input regarding Radio/Microwave;

1 input each regarding Lasers and Cryogenic/Thermal.

8.2 Observatories:

4 inputs regarding mirrors, antenna, coating

4 inputs regarding structures

1 input regarding formation flying

8.3 In-Situ Instruments/Sensors

5 inputs regarding gravity wave detection

4 inputs regarding atomic clocks

1 input each for neutral ion detection, quantum communication, mineral testing

Conclusion

Technology advancement is required to enable NASA's high priority missions of the future.

To prepare for those missions requires a roadmap of how to get from the current state of the art to where technology needs to be in 5, 10, 15 and 20 years.

SIOSS identifies where substantial enhancements in mission capabilities are needed and provides strategic guidance for the agency's budget formulation and prioritization process.

The initial report was presented to the NRC in Oct 2010 (http://www.nasa.gov/offices/oct/home/roadmaps/index.html). And, the NRC review report is expected in late summer 2011.