Response of NASA OCT Science Instrument, Observatory and Sensor System (SIOSS) to 2012 NRC Technology Roadmap Assessment

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NASA Technology Roadmaps

In 2009/2010 NASA developed Technology Roadmaps

Technology Area 8 was Science Instruments, Observatories & Sensors Systems (SIOSS).

SIOSS included:

- Technology Area Breakdown Structure (TABS)
- Key Technical Challenges
- Roadmaps for Each Level 1 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

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

Mirror Technology Related Challenges

Present to 2016
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
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Other Technology Assessment Observatory Needs

The ability to produce large aperture observatories depends upon advances in other technology assessment areas:

- volume and mass capacities of launch vehicles;
- validated performance models that integrate optical, mechanical, dynamic, and thermal models for telescopes, structures, instruments, and spacecraft to enable the design and manufacture of observatories whose performance requirements are too precise to be tested on the ground;
- new materials and design concepts to enable ultra-stable very large space structures;
- terabit communication; and
- autonomous rendezvous and docking for on-orbit assembly of very large structures.

NASA Technology Roadmaps

In December 2010 NASA published its Technology Roadmaps, then asked the National Research Council to:

Criteria: Establish a set of criteria to enable prioritization of technologies within each and among NASA's technology areas;

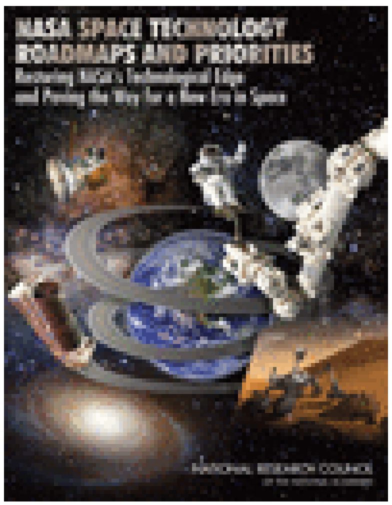
Technologies: Consider technologies that address the needs of NASA's exploration systems, Earth and space science, and space operations mission areas, as well as those that contribute to critical national and commercial needs in space technology;

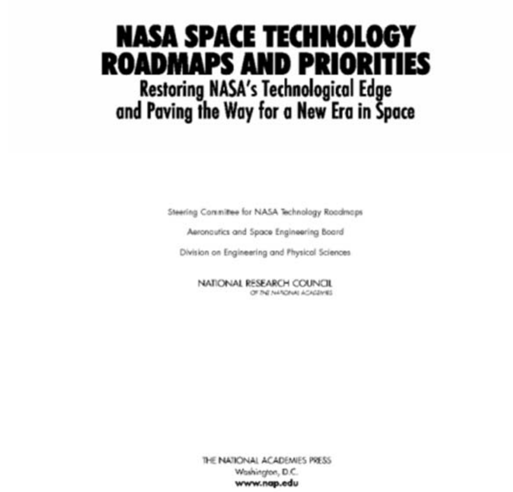
Integration: Integrate the outputs to identify key common threads and issues and to summarize findings and recommendations; and

Prioritization: Prioritize the highest-priority technologies.

NASA Technology Roadmaps

On 1 February 2012, NRC published "NASA Space Technology Roadmaps and Priorities: Restoring NASA's Technological Edge and Paving the Way for a New Era in Space".




NASA SPACE TECHNOLOGY ROADMAPS AND PRIORITIES
Restoring NASA's Technological Edge and Paving the Way for a New Era in Space

Steering Committee for NASA Technology Roadmaps
Aeronautics and Space Engineering Board
Division on Engineering and Physical Sciences

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NASA Mission Objectives

NRC defined 3 Mission Objectives for NASA:

Objective A: Extend and Sustain Human Activities beyond low Earth Orbit.

Objective B: Explore the evolution of the solar systems and the potential for life elsewhere.

Objective C: Expand our understanding of Earth and the Uuniverse in which we live.

Top Technical Challenges

NRC defined top technical challenges to enable each Objective:

TABLE S.2 Top Technical Challenges by Technology Objective

Top Technical Challenges for Technology Objective A: Extend and sustain human activities beyond low Earth orbit.	Top Technical Challenges for Technology Objective B: Explore the evolution of the solar system and the potential for life elsewhere (in-situ measurements).	Top Technical Challenges for Technology Objective C: Expand our understanding of Earth and the universe in which we live (remote measurements).
A1) **Improved Access to Space:** Dramatically reduce the total cost and increase reliability and safety of access to space.	B1) **Improved Access to Space:** Dramatically reduce the total cost and increase reliability and safety of access to space.	C1) **Improved Access to Space:** Dramatically reduce the total cost and increase reliability and safety of access to space.
A2) **Space Radiation Health Effects:** Improve understanding of space radiation effects on humans and develop radiation protection technologies to enable long-duration space missions.	B2) **Precision Landing:** Increase the ability to land more safely and precisely at a variety of planetary locales and at a variety of times.	C2) **New Astronomical Telescopes:** Develop a new generation of astronomical telescopes that enable discovery of habitable planets, facilitate advances in solar physics, and enable the study of faint structures around bright objects by developing high-contrast imaging and spectroscopic technologies to provide unprecedented sensitivity, field of view, and spectroscopy of faint objects.
A3) **Long Duration Health Effects:** Minimize the crew health effects of long duration space missions (other than space radiation).	B3) **Robotic Maneuvering:** Enable mobile robotic systems to autonomously and verifiably navigate and avoid hazards and increase the robustness of landing systems to surface hazards.	C3) **Lightweight Space Structures:** Develop innovative lightweight materials and structures to reduce the mass and improve the performance of space systems such as (1) launch vehicle and payload systems; (2) space and surface habitats that protect the crew, including multifunctional structures that enable lightweight radiation shielding, implement self-monitoring capability, and require minimum crew maintenance time; and (3) lightweight, deployable synthetic aperture radar antennas, including reliable mechanisms and structures for large-aperture space systems that can be stowed compactly for launch and yet achieve high-precision final shapes.

Prioritized 5 Year Technology Investments

NRC prioritized technologies for each Objective in which NASA should invest over the next 5 years.

TABLE S.3 Final Prioritization of the Top Technologies, Categorized by Objective

Highest Priority Technologies for Technology Objective A	Highest Priority Technologies for Technology Objective B	Highest Priority Technologies for Technology Objective C
Radiation Mitigation for Human Spaceflight (X.1)	GN&C (X.4)	Optical Systems (Instruments and Sensors) (8.1.3)
Long-Duration Crew Health (6.3.2)	Solar Power Generation (Photovoltaic and Thermal) (3.1.3)	High Contrast Imaging and Spectroscopy Technologies (8.2.4)
ECLSS (X.3)	Electric Propulsion (2.2.1)	Detectors and Focal Planes (8.1.1)
GN&C (X.4)	Fission Power Generation (3.1.5)	Lightweight and Multifunctional Materials and Structures (X.2)
(Nuclear) Thermal Propulsion (2.2.3)	EDL TPS (X.5)	Active Thermal Control of Cryogenic Systems (14.1.2)
Lightweight and Multifunctional Materials and Structures (X.2)	In-Situ Instruments and Sensors (8.3.3)	Electric Propulsion (2.2.1)
Fission Power Generation (3.1.5)	Lightweight and Multifunctional Materials and Structures (X.2)	Solar Power Generation (Photo-voltaic and Thermal) (3.1.3)
EDL TPS (X.5)	Extreme Terrain Mobility (4.2.1)	

TA8 SIOSS High Priority Technologies

NRC priority ranked SIOSS technologies:

1. High-Contrast Imaging and Spectroscopic Technologies
2. Optical Systems (Instruments and Sensors)
3. Detectors and Focal Planes
4. In-Situ Instruments and Sensors
5. Wireless Spacecraft Technology (really TA05 COM & NAV)
6. Lasers
7. Electronics for Instruments and Sensors

High Contrast Imaging and Spectroscopy

Substantial increases in High-Dynamic Range Imaging, Sensitivity, Field of View and Spectroscopic Resolution are needed to image and take spectra of faint structures around bright objects (for exo-planet science).

Technical approaches include star shades, interferometry and coronagraphy.

TA08 Roadmap Team Response

TA08 Roadmap Team agrees with the Academy

High-Contrast Imaging and Faint Object Spectroscopy are high priority capabilities.

The technologies to enable these capabilities are included in:

TABS 8.1.3 Optical Components (for High-Contrast Imaging and Spectroscopy) and

TABS 8.2 (Low-Cost High-Performance) Observatories.

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- 8.1.1.6 Sub-Kelvin High-Sensitivity Det.

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- 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

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8.2 Observatories

(8.2.1) Large Mirror Systems
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Optical Systems

NRC identified two key technologies:

Active Wavefront Control, and

Grazing-Incidence Optical Systems

Active Wavefront Control could be accomplished with adjustable optics based on thin, slumped glass.

Grazing incidence optical systems (for x-ray and far-UV <50 nm) require 10X better resolution without increasing areal mass. This requires systems for piezo adjustment of thin slumped glass, and in mounting and testing assembled optics.

Also needed are normal incidence mirrors of 4 meter or larger that could operate to wavelengths as low as 30 nm.

TA08 Roadmap Team Response

The TA08 Roadmap Team agrees with the Academy

Low-Cost High-Performance Optical Systems are a high priority.

Technologies to enable such systems are included in:

TABS 8.2 (Low-Cost High-Performance) Observatories and

TABS 8.2.1 Large Optical Systems.

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- 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

Other Recommendations

NRC also made several recommendations regarding the structure of the TA8 SIOSS Roadmap – all were declined.

Recommended Modifications to the TA08 Technology Area Breakdown Structure.	**Response from TA08 Roadmap Team: All Recommendations Declined**
Merge TABS 8.1.3 *Optical Components* with TABS 8.2.1 *Large Mirror Systems* and rename TABS 8.1.3 as *Optical Systems*	Technologies used to manufacture 8.1.3 Optical Components and 8.2.1 Large Mirror Systems are significantly different. Large mirror systems are typically manufactured using macro processes such as machining, grinding and polishing while optical components are usually manufactured using micro processes. TABS 8.1.3 Optical Component technologies are located inside of instruments (between the observatory and focal plane or source) and manipulate EM radiation to aid in the acquisition or transmission of information. TABS 8.2.1 Large Mirror System technologies design, manufacture, and test optical components for large space telescopes operating from x-rays to far-infrared/sub-mm.
Create a TABS for *Space Atomic Interferometry*	Space Atomic Interferometry is a Level 5 technology and is included in TABS 8.3.2.2 Gravitation Wave Sensors.
Create a TABS for *High Contrast Imaging and Spectroscopy Technologies* Create a TABS for *Wireless Spacecraft Technologies*	TA08 recognizes the need to emphasize this area, and suggests that TABS 8.1.3 Optical Components could be renamed TABS 8.1.3 Optical Components for High Contrast Imaging and Spectroscopy. Wireless Spacecraft Technologies is included in TA05 Communications and Navigation Systems.
Merge TABS 8.3.1 *Particles: Charged and Neutral* and 8.3.2 *Fields and Waves*	Technologies for the two TABS are entirely different. There is little overlap in the technologies needed to detect a solar proton and those needed to detect a gravitational wave.
Create a TABS 8.3.4 for *Surface Biology and Chemistry Sensors, sensors to detect and analyze biotic and pre-biotic substances*	TA08 understands the desire to emphasize the surface technologies, but points out that these are already included in TABS 8.3.3 In Situ, namely 8.3.4.2 Chemical and Mineral Assessment, 8.3.4.3 Organic Assessment, and 8.3.4.4 Biological Detection and Characterization. Additionally, because 8.3.3 In-Situ Instruments and Sensors ranked High Priority in Table K.2 (page K-7) and 8.3.4 Surface Biology and Chemistry Sensors ranked only Medium Priority, there is the risk that this important subset of 8.3.3 will be unfairly (unintentionally) reduced in priority.

Conclusion

The final NASA Technology Roadmaps, including each Technology Areas's response to the NRC Assessment have been published and are available on line at:

http://www.nasa.gov/offices/oct/home/roadmaps/index.html

These roadmaps will be updated periodically.