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.

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 2005 Advanced Telescopes and Observatories Capability Roadmap.
SI OSS

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

SI OSS 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
- Earth Science and Applications from Space, NRC Decadal Survey, 2007
- 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>
<thead>
<tr>
<th>Mission</th>
<th>Technology</th>
<th>Metric</th>
<th>State of Art</th>
<th>Need</th>
<th>Start</th>
<th>TRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>WFIRST</td>
<td>NIR detectors</td>
<td>Pixel array</td>
<td>2k x 2k</td>
<td>4k x 4k</td>
<td>10 µm</td>
<td>2012</td>
</tr>
<tr>
<td>UVOTP</td>
<td>Detector arrays:</td>
<td>Low noise</td>
<td>Pixel QE UV QE Visible Rad Hard</td>
<td>2k x 2k</td>
<td>4k x 4k</td>
<td>&gt; 0.5 90-300 nm</td>
</tr>
<tr>
<td>NWTP</td>
<td>Photon counting arrays</td>
<td>Pixel array visible Visible QE Pixel array NIR</td>
<td>512 x 512 80% 450-750 nm 128 x 128</td>
<td>1k x 1k</td>
<td>&gt;80% 450-900 nm</td>
<td>256 x 256</td>
</tr>
<tr>
<td>UVOTP</td>
<td>Far-IR detector arrays</td>
<td>Sens. (NEP W/√Hz) Wavelength Pixels</td>
<td>1e-18</td>
<td>&gt; 250µm 256</td>
<td>3e-20</td>
<td>35-430µm</td>
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<tr>
<td>IXO</td>
<td>X-ray detectors</td>
<td>Pixel array Noise QE Frame rate</td>
<td>10-15 e^- RMS</td>
<td>100 kHz@2e^-</td>
<td>40 x 40 TES 2-4 e^- RMS</td>
<td>&gt; 0.7</td>
</tr>
<tr>
<td>WFIRST</td>
<td>Detector ASIC</td>
<td>Speed @ low noise Rad tolerance</td>
<td>100 kHz</td>
<td>0.5 - 1 MHz</td>
<td>55 krad</td>
<td>2011</td>
</tr>
<tr>
<td>NWTP</td>
<td>Mid-IR Starlight suppress: interferometer</td>
<td>Contrast Passband mid-IR</td>
<td>1.65 x 10^-7; laser 30% at 10 µm</td>
<td>&lt; 1 x 10^-7; broadband</td>
<td>&gt; 50%</td>
<td>8µm</td>
</tr>
<tr>
<td>NWTP</td>
<td>Active WFSC; Deformable Mirrors</td>
<td>Sensing Control (Actuators)</td>
<td>λ/10,000 rms 32 x 32</td>
<td>&lt; λ/10,000 rms 128 x 128</td>
<td>2011</td>
<td>2016</td>
</tr>
<tr>
<td>IXO</td>
<td>XGS CAT grating</td>
<td>Facet size; Throughput</td>
<td>3x3 mm; 5%</td>
<td>60x60mm; 45%</td>
<td>2010</td>
<td>2014</td>
</tr>
<tr>
<td>Various</td>
<td>Filters &amp; coatings</td>
<td>Reflect/transmit; temp</td>
<td>2011</td>
<td>2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Various</td>
<td>Spectroscopy</td>
<td>Spectral range/resolve</td>
<td>2011</td>
<td>2020</td>
<td></td>
<td></td>
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<tr>
<td>SPICA</td>
<td>Continuous sub-K refrigerator</td>
<td>Heat lift Duty cycle</td>
<td>&lt; 1 µW 90 %</td>
<td>&gt; 1 µW 100 %</td>
<td>2011</td>
<td>2015</td>
</tr>
<tr>
<td>IXO</td>
<td>Large X-ray mirror systems</td>
<td>Effective Area HPD Resolution Areal Density; Active structure</td>
<td>0.3 m2</td>
<td>15 arcsec 10 kg/m2; no</td>
<td>&gt;3 m2 (50 m2)</td>
<td>&lt;5 arcsec (&lt;1 as) 1 kg/m2; yes</td>
</tr>
<tr>
<td>NWTP</td>
<td>Large UVOIR mirror systems</td>
<td>Aperture diameter Figure Stability Reflectivity kg/m2 S/m2</td>
<td>2.4 m</td>
<td>&lt; 10 nm rms ---</td>
<td>&gt;60%, 120-900 nm 30 kg/m2 $12M/m2$</td>
<td>3 to 8 m (15 to 30 m) &lt;10 nm rms &lt;9,000 min &gt;60%, 90-1100 nm Depends on LV &lt;$1M/m2$</td>
</tr>
<tr>
<td>WFIRST</td>
<td>Passive stable structure</td>
<td>Thermal stability</td>
<td>Chandra WFOV PSF Stable</td>
<td>2011</td>
<td>2014</td>
<td></td>
</tr>
<tr>
<td>NWTP</td>
<td>Large structure: occulter</td>
<td>Dia; Petal Edge Tol</td>
<td>Not demonstrated</td>
<td>30-80 m; &lt;0.1mm rms</td>
<td>2011</td>
<td>2016</td>
</tr>
<tr>
<td>NWTP</td>
<td>Large, stable telescope structures (Passive or active)</td>
<td>Aperture diameter Thermal/dynamic WFE Line-of-sight jitter kg/m2 S/m2</td>
<td>6.5 m</td>
<td>60 nm rms 1.6 mas 40 kg/m2 $4 M/m2$</td>
<td>8 m (15 to 30 m) &lt;0.1 nm rms 1 mas &lt;20 (or 400) kg/m2 &lt;$2 M/m2$</td>
<td>2011</td>
</tr>
<tr>
<td>LISA</td>
<td>Drag-Free Flying Occulter Flying</td>
<td>Residual accel Range Lateral alignment</td>
<td>3x10^-16 m/s^2/√Hz</td>
<td>3x10^-9 m/s^2/√Hz 10,000 to 80,000 km &gt;0.7 m wrt LOS</td>
<td>2011</td>
<td>2016</td>
</tr>
<tr>
<td>NWTP</td>
<td>Formation flying: Sparse &amp; Interferometer</td>
<td>Position/pointing #: Separation</td>
<td>5cm/6.7 arcmin 2; 2; 2 m</td>
<td>5; 15-400-m</td>
<td>2011</td>
<td>2020</td>
</tr>
<tr>
<td>LISA</td>
<td>Gravity wave sensor Atomic interferometer</td>
<td>Spacetime Strain Bandpass</td>
<td>N/A</td>
<td>1x10^-16/√Hz, 0.1-100mHz</td>
<td>2013</td>
<td>2019</td>
</tr>
<tr>
<td>Various</td>
<td>Communication</td>
<td>Bits per sec</td>
<td>Terra bps</td>
<td>2014</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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.
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

Missions

8.1.1 Detectors/Focal Planes
- NIR Array
- NIR Photon
- X-ray microcalorimeter
- CMB-Pol Detector
- UV/Optical Detector

8.1.2 Electronics
- Low Noise Readout

8.1.3 Optical Components
- Thermal Stable Receiver
- Starlight Suppression
- Wavefront Control
- UV/Optical Components

8.1.4 Micro Radio T/R
8.1.5 Lasers
8.1.6 Cryocoolers

8.2 Instruments

8.2.1 Mirrors
- WFOV Imager
- X-Ray Mirrors
- Large UV/O mirrors

8.2.2 Structures & Antenna
- Distributed Aperture

8.2.3 Distributed Aperture Occulter

8.3 Sensor

8.3.1 Particle, Fields & Waves
- Gravity Wave Sensor System

8.3.2 In-Situ

2010 2015 2020 2025 2030

- Major Decision
- Major Event / Accomplishment / Milestone
- Decadal
- TRL 6
- Technology Push
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 precision mirrors, 5 to 10 nm rms, <$2M/m^2$, <30kg/m^2
- X-ray: <5 arc second resolution, < $0.1M/m^2$ (surface normal space), <3 kg/m^2

**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: $5\mu$cy/$\sqrt{Hz}$, 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 m^2 aperture, < 10 nm rms surface, < 1 mas pointing, < 15 nm rms stability, < $2M/m^2$

**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.

SI OSS 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.