Summary of the NASA Science Instrument, Observatory and Sensor System (SIOSS) Technology Assessment

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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)

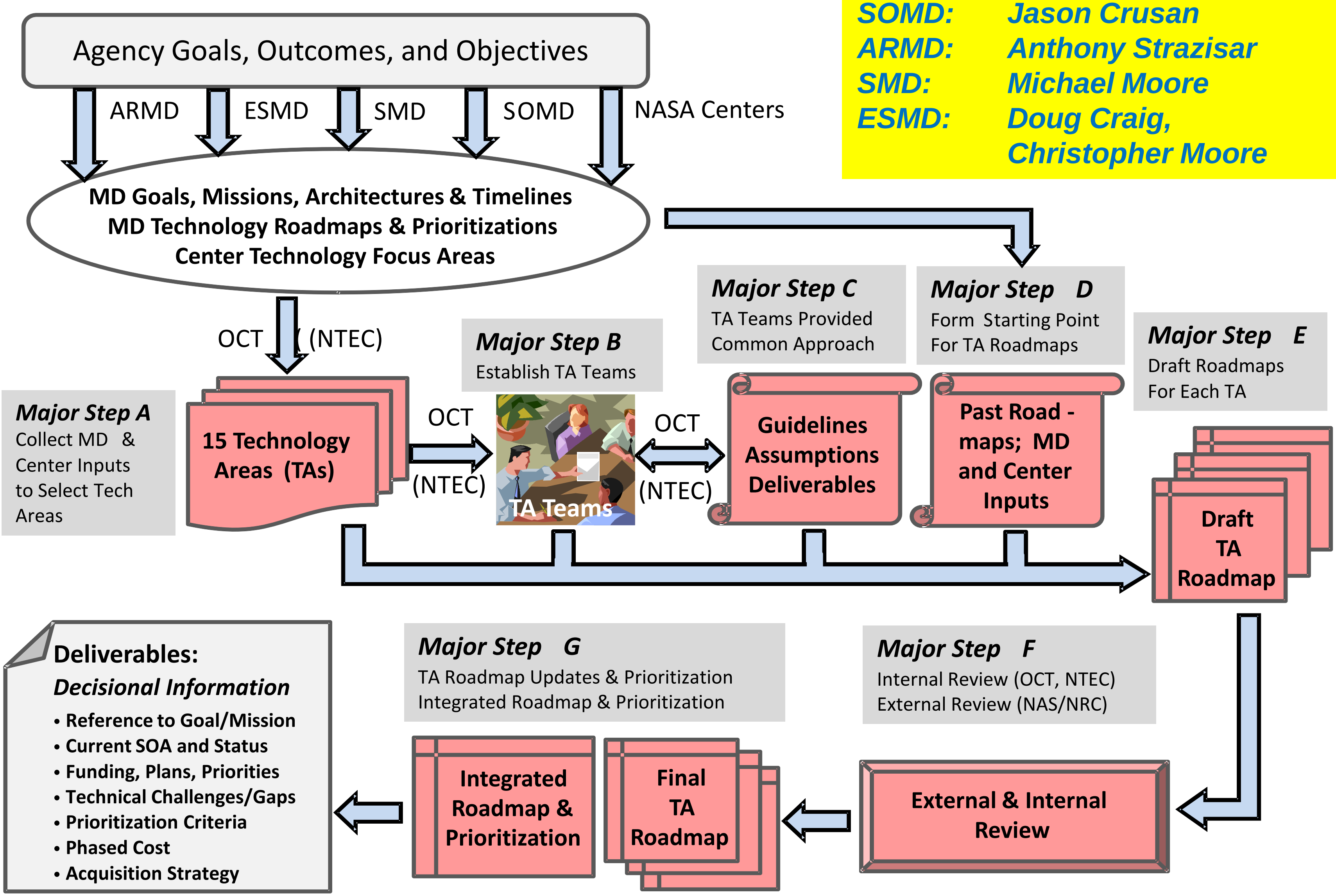
July 2010, NASA Office of Chief Technologist (OCT) initiated an activity to create and maintain a NASA integrated roadmap for 15 key technology areas which recommend an overall technology investment strategy and prioritize NASA's technology programs to meet NASA's strategic goals.

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.

A-STAR Process

SOMD: *Jason Crusan*
ARMD: *Anthony Strazisar*
SMD: *Michael Moore*
ESMD: *Doug Craig, Christopher Moore*



Agency Goals, Outcomes, and Objectives

ARMD

ESMD

SMD

SOMD

NASA Centers

MD Goals, Missions, Architectures & Timelines
MD Technology Roadmaps & Prioritizations
Center Technology Focus Areas

OCT (NTEC)

Major Step A
Collect MD & Center Inputs to Select Tech Areas

15 Technology Areas (TAs)

OCT (NTEC)

Major Step B
Establish TA Teams

TA Teams

OCT (NTEC)

Major Step C
TA Teams Provided Common Approach

Guidelines Assumptions Deliverables

Major Step D
Form Starting Point For TA Roadmaps

Past Road - maps; MD and Center Inputs

Major Step E
Draft Roadmaps For Each TA

Draft TA Roadmap

Major Step F
Internal Review (OCT, NTEC)
External Review (NAS/NRC)

External & Internal Review

Major Step G
TA Roadmap Updates & Prioritization
Integrated Roadmap & Prioritization

Final TA Roadmap

Integrated Roadmap & Prioritization

Deliverables:

Decisional Information

- **Reference to Goal/Mission**
- **Current SOA and Status**
- **Funding, Plans, Priorities**
- **Technical Challenges/Gaps**
- **Prioritization Criteria**
- **Phased Cost**
- **Acquisition Strategy**

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.

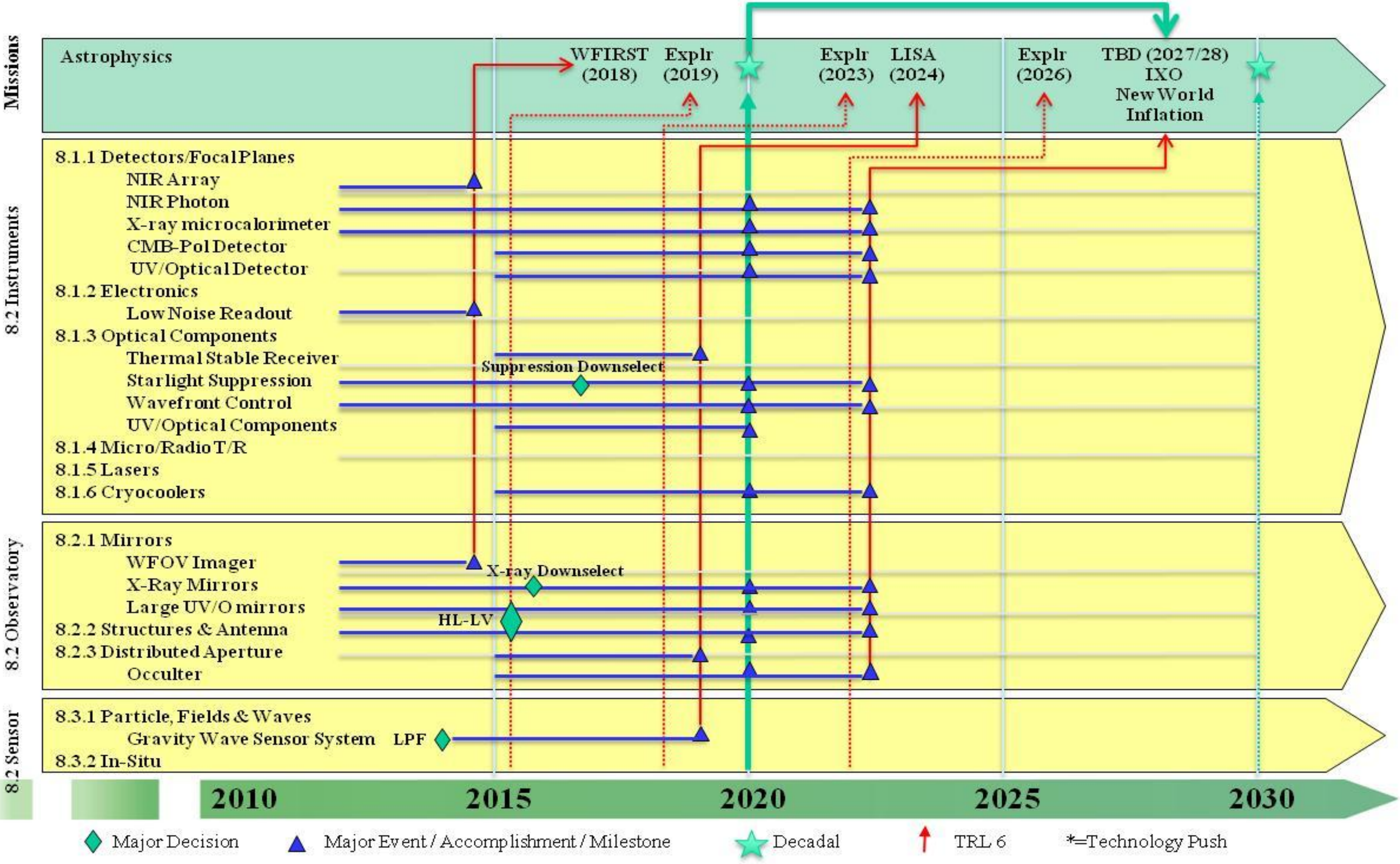
Each technology need has specific maturity milestones (TRL-6).

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



Missions

Astrophysics

WFIRST (2018)

Explr (2019)

Explr (2023)

LISA (2024)

Explr (2026)

TBD (2027/28)
IXO
New World
Inflation

8.2 Instruments

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

Suppression Downselect

8.2 Observatory

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

8.2.2 Structures & Antenna

8.2.3 Distributed Aperture
- Occulter

X-ray Downselect

HL-LV

8.2 Sensor

8.3.1 Particle, Fields & Waves
- Gravity Wave Sensor System

LPF

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

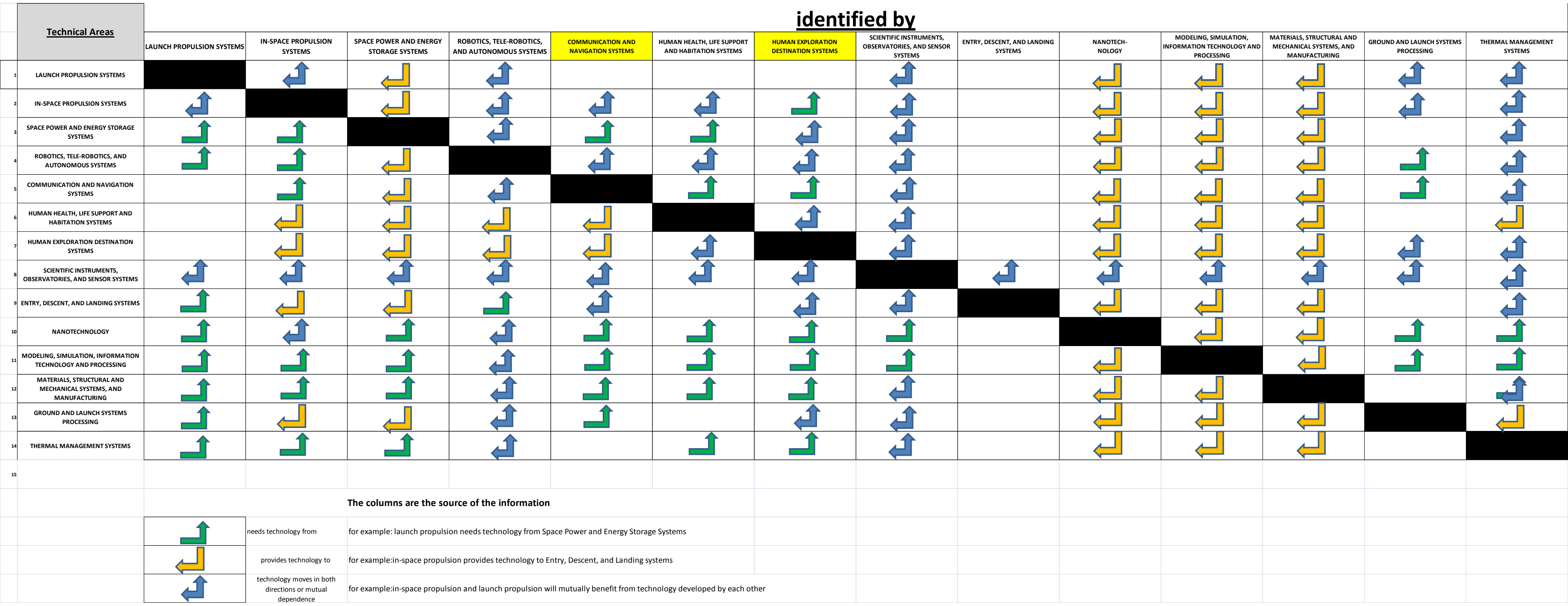
Present to 2016
In-situ Sensors for Mars Sample Returns and In-Situ Analysis Miniaturization, Sample gathering, caching, handling, and analysis In situ drilling and instrumentation
Low-Cost, Large-Aperture Precision Mirrors UV and Optical Lightweight mirrors, 5 to 10 nm rms, <$2M/m2, <30kg/m2 X-ray: <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

Interdependencies with other Technology Areas

Each TA identifies whether

- Its Technology is Required by another TA
- It Needs Technology from another Area
- Technology flows both ways between Tas

SIOSS Technology flows both ways with all other TAs



identified by

	Technical Areas	LAUNCH PROPULSION SYSTEMS	IN-SPACE PROPULSION SYSTEMS	SPACE POWER AND ENERGY STORAGE SYSTEMS	ROBOTICS, TELE-ROBOTICS, AND AUTONOMOUS SYSTEMS	COMMUNICATION AND NAVIGATION SYSTEMS	HUMAN HEALTH, LIFE SUPPORT AND HABITATION SYSTEMS	HUMAN EXPLORATION DESTINATION SYSTEMS	SCIENTIFIC INSTRUMENTS, OBSERVATORIES, AND SENSOR SYSTEMS	ENTRY, DESCENT, AND LANDING SYSTEMS	NANOTECH-NOLOGY	MODELING, SIMULATION, INFORMATION TECHNOLOGY AND PROCESSING	MATERIALS, STRUCTURAL AND MECHANICAL SYSTEMS, AND MANUFACTURING	GROUND AND LAUNCH SYSTEMS PROCESSING	THERMAL MANAGEMENT SYSTEMS
1	LAUNCH PROPULSION SYSTEMS	■	🟦	🟨	🟦				🟦		🟨	🟨	🟨	🟦	🟦
2	IN-SPACE PROPULSION SYSTEMS	🟦	■	🟨	🟦	🟦	🟦	🟩	🟦		🟨	🟨	🟨	🟦	🟦
3	SPACE POWER AND ENERGY STORAGE SYSTEMS	🟩	🟩	■	🟦	🟩	🟩	🟦	🟦		🟨	🟨	🟨		🟦
4	ROBOTICS, TELE-ROBOTICS, AND AUTONOMOUS SYSTEMS	🟩	🟩	🟨	■	🟦	🟦	🟦	🟦		🟨	🟨	🟨	🟩	🟦
5	COMMUNICATION AND NAVIGATION SYSTEMS		🟩	🟨	🟦	■	🟩	🟩	🟦		🟨	🟨	🟨	🟩	🟦
6	HUMAN HEALTH, LIFE SUPPORT AND HABITATION SYSTEMS		🟨	🟨	🟨	🟨	■	🟦	🟦		🟨	🟨	🟨		🟨
7	HUMAN EXPLORATION DESTINATION SYSTEMS		🟨	🟨	🟨	🟨	🟦	■	🟦		🟨	🟨	🟨	🟦	🟦
8	SCIENTIFIC INSTRUMENTS, OBSERVATORIES, AND SENSOR SYSTEMS	🟦	🟦	🟦	🟦	🟦	🟦	🟦	■	🟦	🟦	🟦	🟦	🟦	🟦
9	ENTRY, DESCENT, AND LANDING SYSTEMS	🟩	🟨	🟨	🟩	🟦		🟦	🟦	■	🟨	🟨	🟨		🟦
10	NANOTECHNOLOGY	🟩	🟦	🟩	🟦	🟩	🟩	🟩	🟩		■	🟨	🟨	🟩	🟩
11	MODELING, SIMULATION, INFORMATION TECHNOLOGY AND PROCESSING	🟩	🟩	🟩	🟦	🟩	🟩	🟩	🟩		🟨	■	🟨	🟩	🟩
12	MATERIALS, STRUCTURAL AND MECHANICAL SYSTEMS, AND MANUFACTURING	🟩	🟩	🟩	🟦	🟩	🟩	🟩	🟦		🟨	🟨	■		🟦
13	GROUND AND LAUNCH SYSTEMS PROCESSING	🟩	🟨	🟨	🟦	🟩		🟦	🟦		🟨	🟨	🟨	■	🟨
14	THERMAL MANAGEMENT SYSTEMS	🟩	🟩	🟩	🟦		🟩	🟩	🟦		🟨	🟨	🟨		■
15															

The columns are the source of the information

🟩	needs technology from	for example: launch propulsion needs technology from Space Power and Energy Storage Systems
🟨	provides technology to	for example:in-space propulsion provides technology to Entry, Descent, and Landing systems
🟦	technology moves in both directions or mutual dependence	for example:in-space propulsion and launch propulsion will mutually benefit from technology developed by each other

Interdependencies with other Technology Areas

SIOSS technologies have interdependencies with all areas

- long-lived high-power lasers and single photon detectors for optical communication;
- large aperture solar concentrators for space power & solar thermal propulsions;
- machine vision systems to aid human & autonomous operations ranging from the assembly of flight hardware to AR&D to 3D terrain descent imaging;
- sub-20K cryo-coolers for infrared to far-infrared optical systems and detectors.

Table 3-1 Interdependencies between SIOSS Technology and other Technology Areas

Technology Area	Other TA Technology required by SIOSS	SIOSS Technology required by Other TA
TA1: Launch Propulsion	Affordable access to space, Heavy lift vehicle (PUSH)	Integrated Health Monitoring (IHM) Sensors, Wireless communication source/receiver
TA2: In-Space Propulsion	Electric/ion propulsion, Micro-Newton thrusters, Solar sails, solar electric	IHM Sensors, Solar Power, High Power Lasers, Tracking & Pointing
TA3: Space Power & Storage	Radioisotopes, L2 Power Grid (PUSH)	Photovoltaic Power, Laser Power Beaming,
TA4: Robotics	Rovers, sample acquisition & containment, Aerobots, AR&D; Robotic servicing (PUSH), Robotic assembly (PUSH)	Machine Vision; State Sensors, proximity, tactile; avoidance; telepresence; active ranging
TA5: Com & Nav	Terabit communication; Space Position System; Precision Formation Flying (PUSH)	Optical Communication; Precision Positioning & Laser Ranging; AR&D sensors; Star Trackers; XNAV; Quantum Communication
TA6: Human HAB	Human in-space assembly and service; Human Surface Science (PUSH)	Crew-Protection Sensors; Crew Health Sensors; Space Weather Sensors
TA7: Human Exploration	Heavy lift vehicle (PUSH); Human in-space assembly and servicing (PUSH)	Telescopes to survey NEO population; Instruments for missions to NEOs & other destinations (Moon, Mars, etc.); IHM sensors for spacesuits; High-strength lightweight windows; solar concentrators
TA9: Entry, Descent & Landing	Planetary Descent Systems, Landers, Robots, Airships; Thermal Protection	Terrain tracking and hazard avoidance sensors; IHM Sensors; Planetary atmospheric characterization sensors
TA10: Nano-Technology	Sensors for chemical/bio assessment; High-strength, lightweight, CTE materials; low-power radiation/fault tolerant electronics; nano-lasers; miniaturized instruments; micro-fluidic labs on chip; single-photon counting sensors; nano-thrusters for formation flying	Nanodevices are produced using optical lithographic methods
TA11: Modeling	Validated integrated performance modeling & model-based systems engineering	Validation Data Sensors
TA12: Materials & Structures	Low-density, high stiffness, low-CTE materials for large, deployable or assembly, active or passive, ultra-stiff/stable, precision structures (PUSH)	IHM systems; NDE systems; dimensional and positional characterization; Habitat Windows
TA13: Ground/Launch Sys	Ability to integrate very large science missions	IHM systems; corrosion detection; anomalous conditions monitoring; NDE systems; Communication
TA14: Thermal Management	Sub-20K Cryo-Coolers, Low-Power Cryocoolers	Optical emissivity coatings

Benefits to Other National Needs

SIOSS Technologies have potential benefit for a wide range of national needs, organizations and agencies:

- National Atmospheric and Oceanic Administration (NOAA)
- Department of Defense (DoD)
- Commercial Space Imaging Companies
- Department of Homeland Security (DHS)
- Department of Energy
- Department of Health and Human Services
- Food and Drug Administration
- Environmental Protection Agency

Benefits to Other National Needs

- Detectors/Focal Planes
  - Light-weight, small-size, low-power surveillance and night vision cameras
  - Imaging Spectroscopy (aka Hyperspectral) Systems
  - Remote precision thermometry for surface-activity and energy-use sensing
  - Remote detection, identification, and quantification of gases
- Micro/Radio transmit/receive (T/R) technologies
  - Dept. of Homeland Security detection systems, extending to THz systems
- Lasers
  - Remote sensing of surface properties
  - High-bandwidth communications
- Cryocoolers
  - Terrestrial precision metrology, quantum instruments
- Mirrors/optics
  - Segmented Mirrors; Space Reconnaissance
- Structures and Antennas
  - Synthetic and distributed aperture antennas
- Particle, Fields, and Waves
  - Radiation detectors
- In-Situ (unattended monitoring)
  - Toxic-substance monitors; Lab-on-a-chip applications

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

Astrophysics Budget Planning

The Decadal Survey recommended technology funding for:

1) Future missions at a level of ~10% of NASA's anticipated budget for each mission to reduce risk and cost;

2) *New Worlds*, *Inflation Probe* and *Future UV-Optical Space Capability Definition* Technology Programs to prepare for missions beyond 2020; and

3) "General" technology to define, mature, and select approaches for future competed missions, and "Blue sky" technology to provide transformational improvements in capability and enable undreamed of missions.

Astrophysics Budget Planning

Recommended Program and Technology Development

Program	10-yr Total	2012	2021
IXO	$200M	$4M/yr	$30M/yr
Inflation Probe	$ 60 to $200M	$4M/yr	$30M/yr
New Worlds	$100 to $200M	$4M/yr	$30M/yr
UV-Optical	$ 40M	$2M/yr	$10M/yr

Recommended Augmentations to current $40M/yr Investment

Advanced Tech	$5M/yr
APRA	$20M (25% increase)
Intermediate Tech	$100M ($2M/yr now to $15M/yr by 2021)

10-yr Total is $1 to $1.2B for TA8 SIOSS

This Total should be split primarily between TABS 8.1 Science Instruments and TABS 8.2 Observatory.

Astrophysics has limited TABLS 8.3 Sensor Systems needs.

Astrophysics Budget Planning

Decadal recommended a 10-yr Budget of $1B to $1.2B

Assuming that all Decadal Recommendations are for External Funding, it is necessary to also define a NASA internal budget.

Assume NASA Internal Funding = 50% of External Funding

- Allocated 75% of NASA Funding to Labor
- Allocated 25% of NASA Funding to ODC
- Thus $60M/yr = approx 200 FTEs/yr and $15M/yr ODC

This gives a Total TA8 SIOSS 10-ry Budget of $1.5B to $1.8B just to support the needs of Astrophysics, for example:

8.1 Science Instruments	$ 800 M
8.2 Observatory	$ 600 M
8.3 Sensor Systems	$ 200 M

Decadal Analysis

Similar analysis is required for the other Science Mission Directorate Decadal Reports:

- Earth Science
- Heliophysics
- Planetary

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.

BACKUP

Earth Science Technology Needs

Earth Science requires 4 areas:

- Advance antennas, receivers, transmitters, signal- and data-processing electronics, and cryo coolers.
- Improve low-areal density telescopes in the 1-m range, filters and coatings; advance low noise/highly efficient detectors, and focal planes with readout integrated circuits (ROIC); complementary detector arrays, electronics, cryo coolers and data processing systems and passive hyperspectral/multispectral/imagers, (UV-Vis-IR-FIR) and spectrometers (0.3 to 50 µm)
- Advance lasers in 0.3-2.0 µm range (high power, multi-beam/multi-wavelength, pulsed, and continuous wave), detectors, receivers, larger collecting optics, and scanning mechanisms (including pointing and scanning at high angular resolution); improved quantum efficiency detectors, long-life, high-power laser diode arrays; high damage threshold optics
- Large telescope and RF antenna enable future climate and weather applications.

Table 2.2.1.2-1: Summary of Earth Science Technology Needs

Mission	Technology	Metric	State of Art	Need	Start	TRL6
ASCENDS	Multi-freq laser 0.765/1.572/2.05 µm Pulsed	Output energy Rep rate Efficiency	25 µJ/25 µJ/30mJ 10kHz/50 Hz <2/4%	>3/3/65 mJ 10kHz/10kHz/50 Hz 3.5/7/10%	2012	2014
	1.6 µm CW laser	Power/module/efficiency	5W/7/8%	35W/1/10%	2012	2014
	1.26 µm CW laser	Power/module/efficiency	4W/1/3%	20W/1/8%	2012	2014
	1.57 µm detector	QE/gain/bandwidth		10%/300/10 MHz	2012	2015
	2 µm APD detector	QE/Bandwidth NEP	> 55%/10 MHz 10^{-11} W/Hz$^{1/2}$	>55%/ >500 MHz 10^{-14} W/Hz$^{1/2}$	2012	2014
SWOT	Ka-band power switch matrix	Power capacity	~ 500 W peak	2.5 kW peak, 110-165W avg.; Stable	2012	2015
	Ka-band receiver	Phase stability, isolation Bandwidth	~ 50 mdeg, 68 dB, 80 MHz	~40 mdeg over 3min, >80 dB, >200MHz	2012	2015
	Deployable-antenna structure	Boom length Pointing stability	6.5 m ~0.05 arsec roll	10-14 m 0.005 arcsec roll/3min	2012	2015
HyspIRI	TIR spectrometer (8ch, 3-12 µm)	Frame rate	~ 1 Mpixels/sec	256 Mpixels/sec at 14bits; 32 kHz	2012	2016
GEO-CAPE	UV-Vis-NIR spectrometer ROIC	Size, pixel pitch, frame rate, quantization, QE		1024x2048, <13µm, 4MHz,16bit, >60%uv	2013	2019
ACE	Damage-resistant UV laser at 355 nm	Energy, repetition rate efficiency, lifetime	250mJ/100 Hz/5%	300 mJ, 100Hz, 10%, 3-5 Yrs	2012	2019
	CCD Array (355/ 532 nm)	QE, sampling rate		> 70%/90%, > 5MHz	2012	2019
	Multi-angle polarimeter ROIC	High-processing speed @ low noise	~100 kpix/sec	>10 Mpix/sec <40 electrons	2012	2019
	W-band radar deployable antenna	Reflector diameter Surface accuracy	1.5mm rms@ 5 M	Main 5-6 m; sub4-5m <0.1 mm RMS	2013	2019
	W/Ka-band dual-freq. reflect array	# Elements		W-band: 2500 Ka-band: 900	2013	2019
LIST	Photon-counting det	QE	20% in a 4 x 4 arr	50% in a 1 x 1000 arr	2011	2018
	Laser altimeter (1µm)	Wallplug efficiency Multi-beam array PRF	~10% 9@222µJ/beam	20% 1000 @ 100µJ/beam 10 kHz	2012	2018
PATH	Correlator	Power level	224µW@375MHz	250 µW @ 1 GHz	2014	2020
	Low-mass, low-noise receiver	Noise level, power, mass, frequencies	500 K	400 K, < 50 mW, <150g, 60 - 183 GHz	2014	2020
GRACE-2	Accelerometer	Acceleration accuracy	1e-11 m/s/s	< 1e-12 m/s/s, 1-100s	2018	2021
SCLP	Dual-polarized multi-frequency feed array	Frequency bands Polarization Scanning range		9.6 to 17.2 GHz H and V for all freq >10-20 degrees	2017	2022
GACM	Stable sub- mm scanning antenna	Size, surface accuracy Areal density	1.8 m, 10 µm rms 10 kg/m^2	4 m, 10 µm rms <10kg/m^2	2015	2023
	Radiation-tolerant, digital spectrometer	Bandwidth Efficiency Channels	0.75 GHz 6 W/GHz 4000	8 GHz <1.5 W/GHz 8000	2018	2023
push	UV laser at 305-308nm / 320-325nm	Efficiency, Output Energy	100mj	50mj	2012	2023
3-D Winds	Multi-freq laser - 2/1 µm pulsed	Output energy/rep rate/ WPE/laser lifetime	250/5Hz/2% at 2um	250/500 mJ/5/200Hz, 5%/12%, 500M/15B shots	2014	2024
	- 2 µm CW seed laser	Power	60 mW	100 mW	2014	2024
	Damage-resistant 355 nm pulsed laser	Output energy; pulse rep rate; WPE; life		320-32mJ/pulse; 120-1500 Hz; >5%; 3 yrs	2014	2024
	Lightweight mirrors	Diameter; areal density		> 0.7 m; <6 kg/m^2	2018	2024

Heliophysics Technology Needs

Heliophysics requires 5 areas:

- UV and EUV detectors (sensitivity, solar blindness, array size, and pixel counts)
- Reduce noise and insensitivity of electronics and detectors to heat and radiation
- Improve UV and EUV optical components (coating reflectivity and polarization uniformity, grating efficiency, and surface figure quality)
- Improve cryo-coolers for IR detectors
- Improve in-situ particle sensor- aperture size and composition identification.

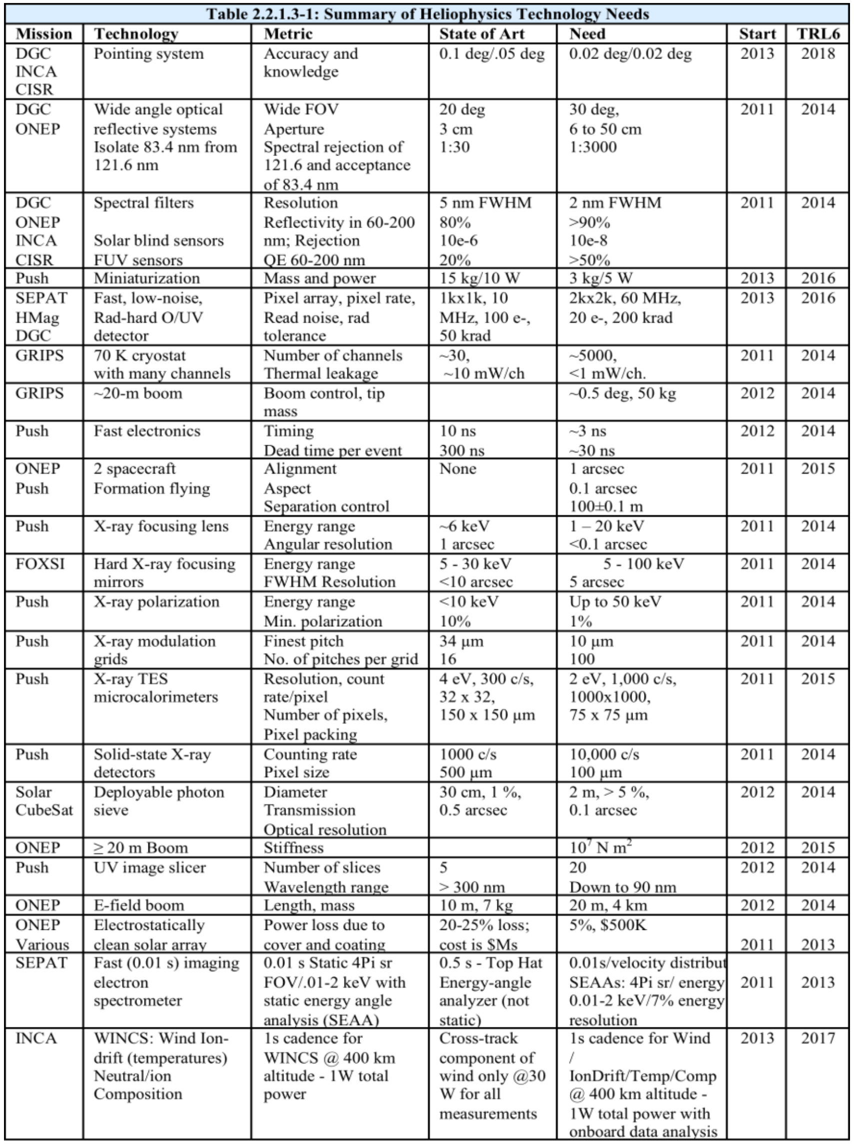


Table 2.2.1.3-1: Summary of Heliophysics Technology Needs

Mission	Technology	Metric	State of Art	Need	Start	TRL6
DGC INCA CISR	Pointing system	Accuracy and knowledge	0.1 deg/.05 deg	0.02 deg/0.02 deg	2013	2018
DGC ONEP	Wide angle optical reflective systems Isolate 83.4 nm from 121.6 nm	Wide FOV Aperture Spectral rejection of 121.6 and acceptance of 83.4 nm	20 deg 3 cm 1:30	30 deg, 6 to 50 cm 1:3000	2011	2014
DGC ONEP INCA CISR	Spectral filters Solar blind sensors FUV sensors	Resolution Reflectivity in 60-200 nm; Rejection QE 60-200 nm	5 nm FWHM 80% 10e-6 20%	2 nm FWHM >90% 10e-8 >50%	2011	2014
Push	Miniaturization	Mass and power	15 kg/10 W	3 kg/5 W	2013	2016
SEPAT HMag DGC	Fast, low-noise, Rad-hard O/UV detector	Pixel array, pixel rate, Read noise, rad tolerance	1kx1k, 10 MHz, 100 e-, 50 krad	2kx2k, 60 MHz, 20 e-, 200 krad	2013	2016
GRIPS	70 K cryostat with many channels	Number of channels Thermal leakage	~30, ~10 mW/ch	~5000, <1 mW/ch.	2011	2014
GRIPS	~20-m boom	Boom control, tip mass		~0.5 deg, 50 kg	2012	2014
Push	Fast electronics	Timing Dead time per event	10 ns 300 ns	~3 ns ~30 ns	2012	2014
ONEP Push	2 spacecraft Formation flying	Alignment Aspect Separation control	None	1 arcsec 0.1 arcsec 100±0.1 m	2011	2015
Push	X-ray focusing lens	Energy range Angular resolution	~6 keV 1 arcsec	1 – 20 keV <0.1 arcsec	2011	2014
FOXSI	Hard X-ray focusing mirrors	Energy range FWHM Resolution	5 - 30 keV <10 arcsec	5 - 100 keV 5 arcsec	2011	2014
Push	X-ray polarization	Energy range Min. polarization	<10 keV 10%	Up to 50 keV 1%	2011	2014
Push	X-ray modulation grids	Finest pitch No. of pitches per grid	34 µm 16	10 µm 100	2011	2014
Push	X-ray TES microcalorimeters	Resolution, count rate/pixel Number of pixels, Pixel packing	4 eV, 300 c/s, 32 x 32, 150 x 150 µm	2 eV, 1,000 c/s, 1000x1000, 75 x 75 µm	2011	2015
Push	Solid-state X-ray detectors	Counting rate Pixel size	1000 c/s 500 µm	10,000 c/s 100 µm	2011	2014
Solar CubeSat	Deployable photon sieve	Diameter Transmission Optical resolution	30 cm, 1 %, 0.5 arcsec	2 m, > 5 %, 0.1 arcsec	2012	2014
ONEP	≥ 20 m Boom	Stiffness		10^7 N m^2	2012	2015
Push	UV image slicer	Number of slices Wavelength range	5 > 300 nm	20 Down to 90 nm	2012	2014
ONEP	E-field boom	Length, mass	10 m, 7 kg	20 m, 4 km	2012	2014
ONEP Various	Electrostatically clean solar array	Power loss due to cover and coating	20-25% loss; cost is $Ms	5%, $500K	2011	2013
SEPAT	Fast (0.01 s) imaging electron spectrometer	0.01 s Static 4Pi sr FOV/.01-2 keV with static energy angle analysis (SEAA)	0.5 s - Top Hat Energy-angle analyzer (not static)	0.01s/velocity distribut SEAAs: 4Pi sr/ energy 0.01-2 keV/7% energy resolution	2011	2013
INCA	WINCS: Wind Ion-drift (temperatures) Neutral/ion Composition	1s cadence for WINCS @ 400 km altitude - 1W total power	Cross-track component of wind only @30 W for all measurements	1s cadence for Wind / IonDrift/Temp/Comp @ 400 km altitude - 1W total power with onboard data analysis	2013	2017

Planetary Science Technology Needs

Planetary Science needs:

- Active spectroscopy and lasers
- Chemical and mineralogy assessment for Inner Planets missions
- Sample caching, handling and screening for Mars sample return
- Radiation-hardened electronics technology for Outer Planets missions
- Mass spectroscopy and organic detection technologies for missions to Saturn/Titan
- Sample gathering, handling and analysis for future Small Bodies mission.

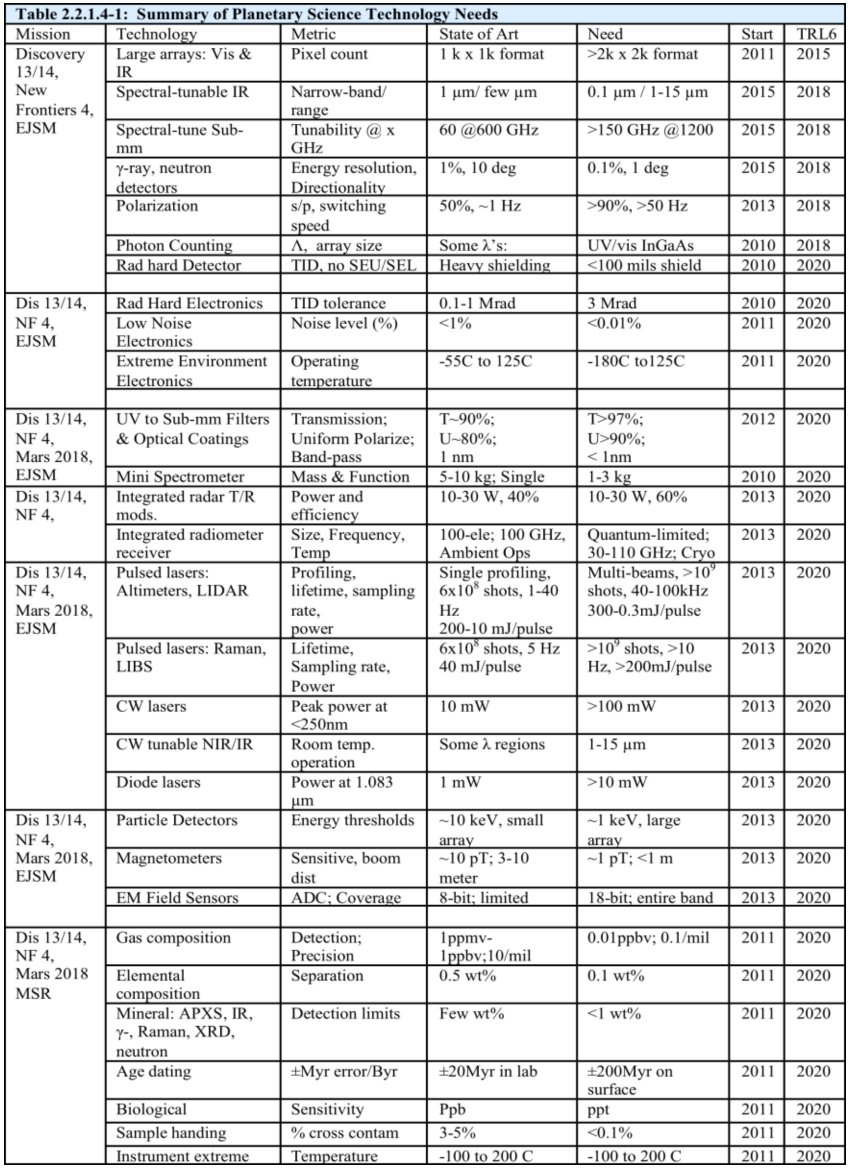


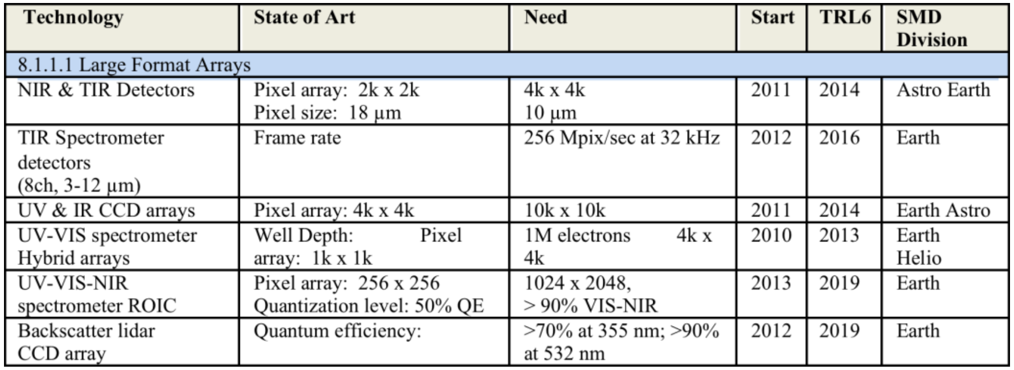
Table 2.2.1.4-1: Summary of Planetary Science Technology Needs

Mission	Technology	Metric	State of Art	Need	Start	TRL6
Discovery 13/14, New Frontiers 4, EJSM	Large arrays: Vis & IR	Pixel count	1 k x 1k format	>2k x 2k format	2011	2015
	Spectral-tunable IR	Narrow-band/ range	1 µm/ few µm	0.1 µm / 1-15 µm	2015	2018
	Spectral-tune Sub-mm	Tunability @ x GHz	60 @600 GHz	>150 GHz @1200	2015	2018
	γ-ray, neutron detectors	Energy resolution, Directionality	1%, 10 deg	0.1%, 1 deg	2015	2018
	Polarization	s/p, switching speed	50%, ~1 Hz	>90%, >50 Hz	2013	2018
	Photon Counting	Λ, array size	Some λ's:	UV/vis InGaAs	2010	2018
	Rad hard Detector	TID, no SEU/SEL	Heavy shielding	<100 mils shield	2010	2020
Dis 13/14, NF 4, EJSM	Rad Hard Electronics	TID tolerance	0.1-1 Mrad	3 Mrad	2010	2020
	Low Noise Electronics	Noise level (%)	<1%	<0.01%	2011	2020
	Extreme Environment Electronics	Operating temperature	-55C to 125C	-180C to125C	2011	2020
Dis 13/14, NF 4, Mars 2018, EJSM	UV to Sub-mm Filters & Optical Coatings	Transmission; Uniform Polarize; Band-pass	T~90%; U~80%; 1 nm	T>97%; U>90%; < 1nm	2012	2020
	Mini Spectrometer	Mass & Function	5-10 kg; Single	1-3 kg	2010	2020
Dis 13/14, NF 4,	Integrated radar T/R mods.	Power and efficiency	10-30 W, 40%	10-30 W, 60%	2013	2020
	Integrated radiometer receiver	Size, Frequency, Temp	100-ele; 100 GHz, Ambient Ops	Quantum-limited; 30-110 GHz; Cryo	2013	2020
Dis 13/14, NF 4, Mars 2018, EJSM	Pulsed lasers: Altimeters, LIDAR	Profiling, lifetime, sampling rate, power	Single profiling, 6x10^8 shots, 1-40 Hz 200-10 mJ/pulse	Multi-beams, >10^9 shots, 40-100kHz 300-0.3mJ/pulse	2013	2020
	Pulsed lasers: Raman, LIBS	Lifetime, Sampling rate, Power	6x10^8 shots, 5 Hz 40 mJ/pulse	>10^9 shots, >10 Hz, >200mJ/pulse	2013	2020
	CW lasers	Peak power at <250nm	10 mW	>100 mW	2013	2020
	CW tunable NIR/IR	Room temp. operation	Some λ regions	1-15 µm	2013	2020
	Diode lasers	Power at 1.083 µm	1 mW	>10 mW	2013	2020
Dis 13/14, NF 4, Mars 2018, EJSM	Particle Detectors	Energy thresholds	~10 keV, small array	~1 keV, large array	2013	2020
	Magnetometers	Sensitive, boom dist	~10 pT; 3-10 meter	~1 pT; <1 m	2013	2020
	EM Field Sensors	ADC; Coverage	8-bit; limited	18-bit; entire band	2013	2020
Dis 13/14, NF 4, Mars 2018 MSR	Gas composition	Detection; Precision	1ppmv-1ppbv;10/mil	0.01ppbv; 0.1/mil	2011	2020
	Elemental composition	Separation	0.5 wt%	0.1 wt%	2011	2020
	Mineral: APXS, IR, γ-, Raman, XRD, neutron	Detection limits	Few wt%	<1 wt%	2011	2020
	Age dating	±Myr error/Byr	±20Myr in lab	±200Myr on surface	2011	2020
	Biological	Sensitivity	Ppb	ppt	2011	2020
	Sample handing	% cross contam	3-5%	<0.1%	2011	2020
	Instrument extreme	Temperature	-100 to 200 C	-100 to 200 C	2011	2020

Technology Area 8.1 Science Instruments

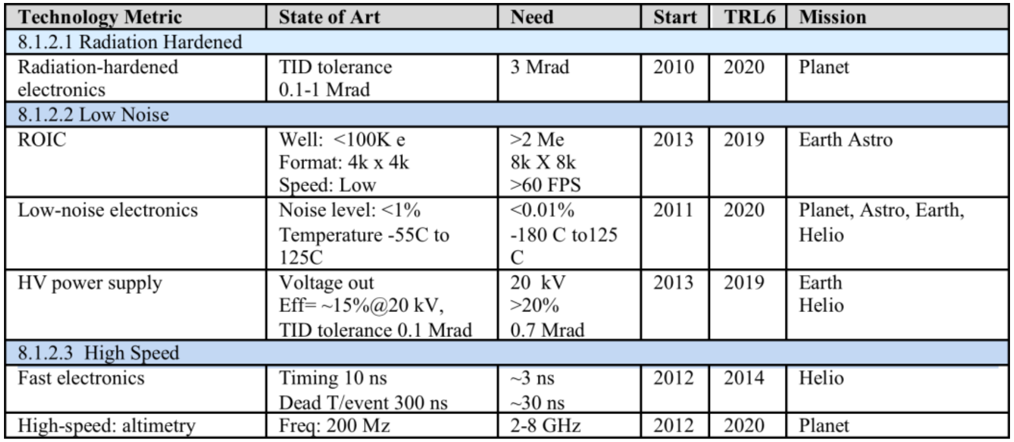
Major challenges include:

- Detectors/Focal Planes: Improve sensitivity and operating temp of single-element and large-array devices.
- Electronics: Radiation-hardened with reduced volume, mass and power.
- Optics: High-throughput with large fields of view, high stability, spectral resolution, and uniformity at many different temperatures.
- Microwave/Radio Transmitters and Receivers: Low-noise amplifier technologies, with reliable low-power high-speed digital- and mixed-signal processing electronics and algorithms.
- Lasers: Reliable, highly stable, efficient, radiation hardened, and long lifetime (>5 years)
- Cryogenic/Thermal Systems: Low power, lightweight, and low vibration



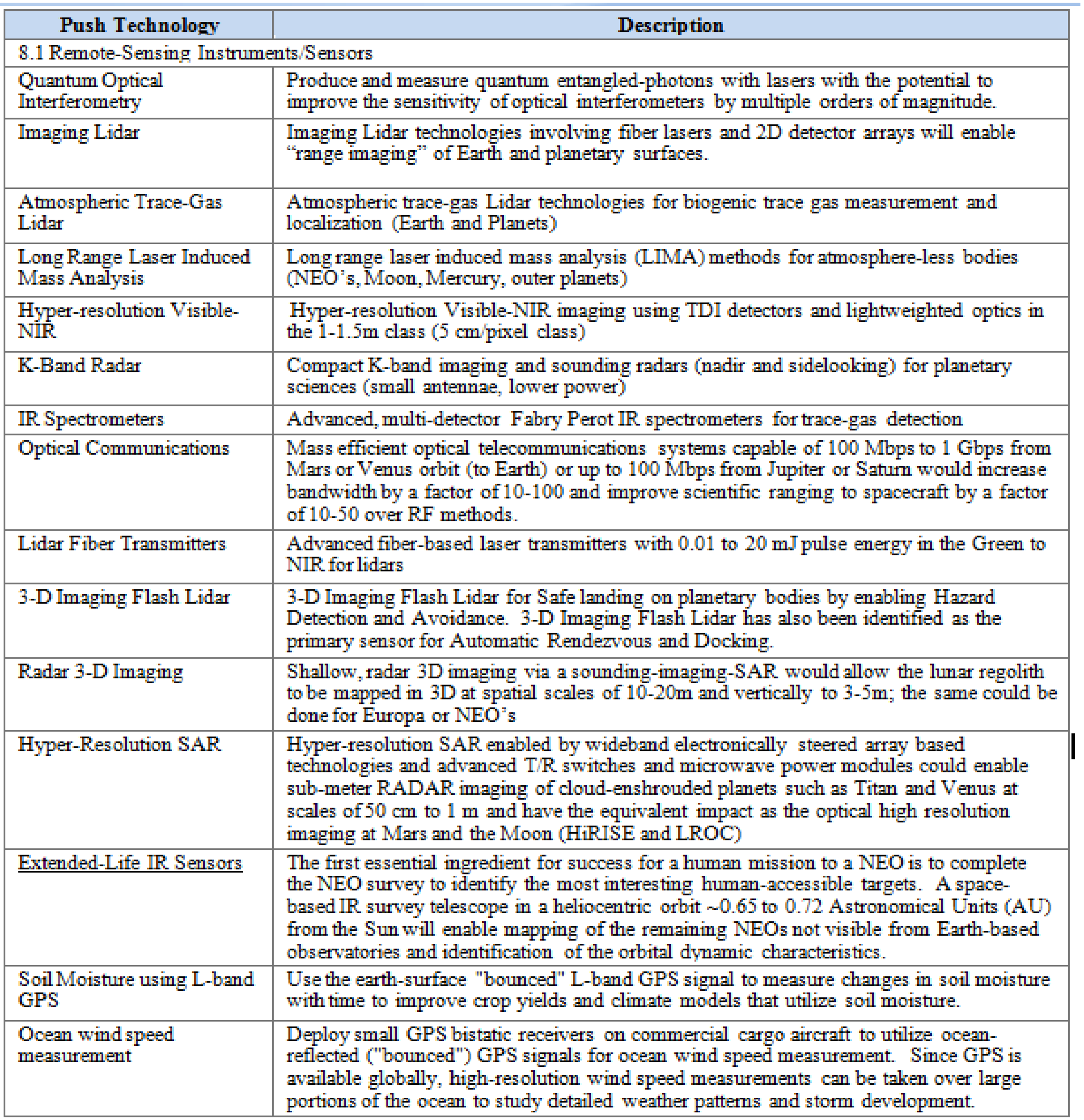
Technology	State of Art	Need	Start	TRL6	SMD Division
8.1.1.1 Large Format Arrays					
NIR & TIR Detectors	Pixel array: 2k x 2k Pixel size: 18 µm	4k x 4k 10 µm	2011	2014	Astro Earth
TIR Spectrometer detectors (8ch, 3-12 µm)	Frame rate	256 Mpix/sec at 32 kHz	2012	2016	Earth
UV & IR CCD arrays	Pixel array: 4k x 4k	10k x 10k	2011	2014	Earth Astro
UV-VIS spectrometer Hybrid arrays	Well Depth: Pixel array: 1k x 1k	1M electrons 4k x 4k	2010	2013	Earth Helio
UV-VIS-NIR spectrometer ROIC	Pixel array: 256 x 256 Quantization level: 50% QE	1024 x 2048, > 90% VIS-NIR	2013	2019	Earth
Backscatter lidar CCD array	Quantum efficiency:	>70% at 355 nm; >90% at 532 nm	2012	2019	Earth

Examples from Table 2.2.2.1-1



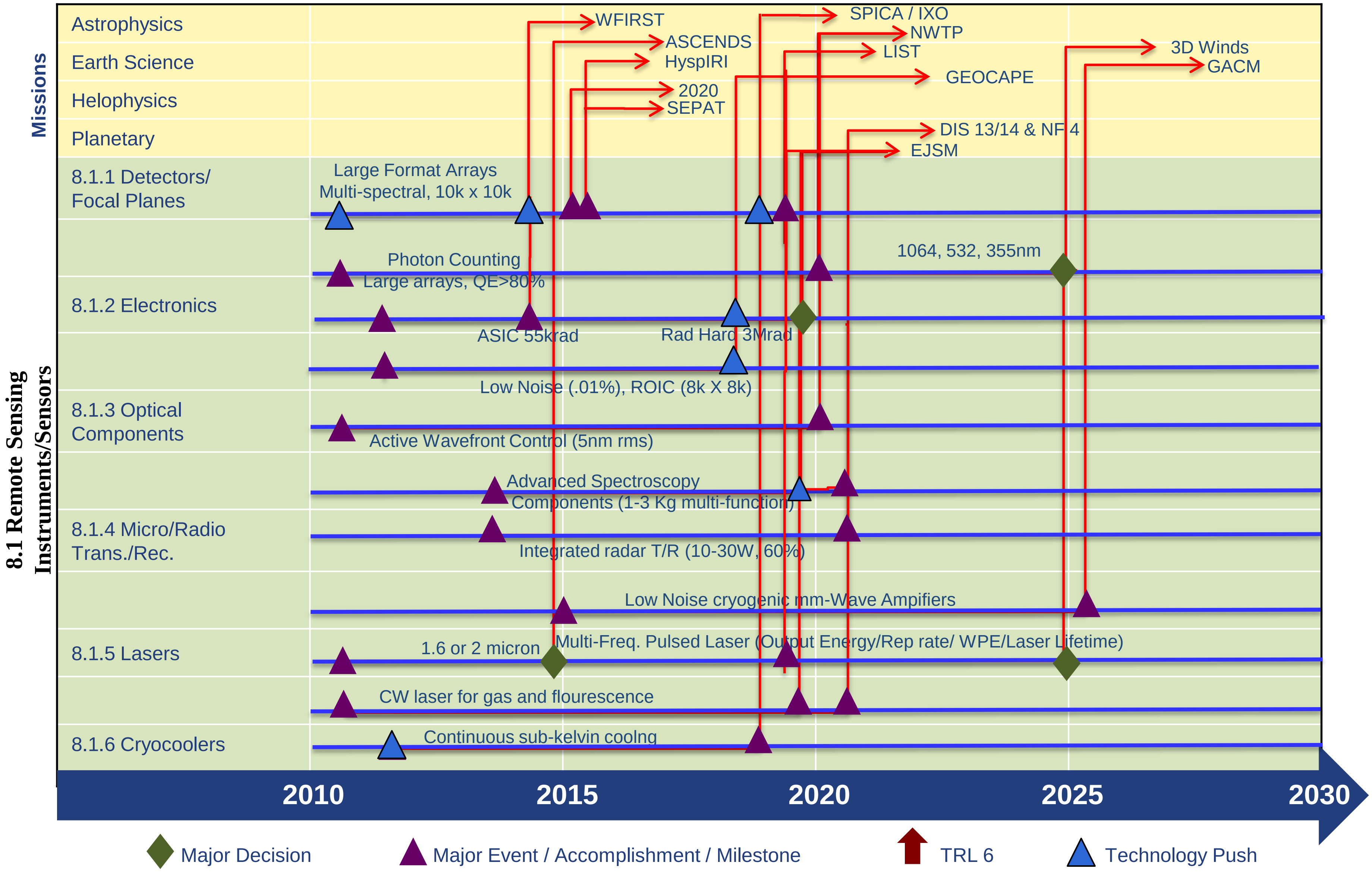
Technology Metric	State of Art	Need	Start	TRL6	Mission
8.1.2.1 Radiation Hardened					
Radiation-hardened electronics	TID tolerance 0.1-1 Mrad	3 Mrad	2010	2020	Planet
8.1.2.2 Low Noise					
ROIC	Well: <100K e Format: 4k x 4k Speed: Low	>2 Me 8k X 8k >60 FPS	2013	2019	Earth Astro
Low-noise electronics	Noise level: <1% Temperature -55C to 125C	<0.01% -180 C to125 C	2011	2020	Planet, Astro, Earth, Helio
HV power supply	Voltage out Eff= ~15%@20 kV, TID tolerance 0.1 Mrad	20 kV >20% 0.7 Mrad	2013	2019	Earth Helio
8.1.2.3 High Speed					
Fast electronics	Timing 10 ns Dead T/event 300 ns	~3 ns ~30 ns	2012	2014	Helio
High-speed: altimetry	Freq: 200 Mz	2-8 GHz	2012	2020	Planet

Push Technologies: 8.1 Science Instruments



Push Technology	Description
8.1 Remote-Sensing Instruments/Sensors	
Quantum Optical Interferometry	Produce and measure quantum entangled-photons with lasers with the potential to improve the sensitivity of optical interferometers by multiple orders of magnitude.
Imaging Lidar	Imaging Lidar technologies involving fiber lasers and 2D detector arrays will enable "range imaging" of Earth and planetary surfaces.
Atmospheric Trace-Gas Lidar	Atmospheric trace-gas Lidar technologies for biogenic trace gas measurement and localization (Earth and Planets)
Long Range Laser Induced Mass Analysis	Long range laser induced mass analysis (LIMA) methods for atmosphere-less bodies (NEO's, Moon, Mercury, outer planets)
Hyper-resolution Visible-NIR	Hyper-resolution Visible-NIR imaging using TDI detectors and lightweighted optics in the 1-1.5m class (5 cm/pixel class)
K-Band Radar	Compact K-band imaging and sounding radars (nadir and sidelooking) for planetary sciences (small antennae, lower power)
IR Spectrometers	Advanced, multi-detector Fabry Perot IR spectrometers for trace-gas detection
Optical Communications	Mass efficient optical telecommunications systems capable of 100 Mbps to 1 Gbps from Mars or Venus orbit (to Earth) or up to 100 Mbps from Jupiter or Saturn would increase bandwidth by a factor of 10-100 and improve scientific ranging to spacecraft by a factor of 10-50 over RF methods.
Lidar Fiber Transmitters	Advanced fiber-based laser transmitters with 0.01 to 20 mJ pulse energy in the Green to NIR for lidars
3-D Imaging Flash Lidar	3-D Imaging Flash Lidar for Safe landing on planetary bodies by enabling Hazard Detection and Avoidance. 3-D Imaging Flash Lidar has also been identified as the primary sensor for Automatic Rendezvous and Docking.
Radar 3-D Imaging	Shallow, radar 3D imaging via a sounding-imaging-SAR would allow the lunar regolith to be mapped in 3D at spatial scales of 10-20m and vertically to 3-5m; the same could be done for Europa or NEO's
Hyper-Resolution SAR	Hyper-resolution SAR enabled by wideband electronically steered array based technologies and advanced T/R switches and microwave power modules could enable sub-meter RADAR imaging of cloud-enshrouded planets such as Titan and Venus at scales of 50 cm to 1 m and have the equivalent impact as the optical high resolution imaging at Mars and the Moon (HiRISE and LROC)
Extended-Life IR Sensors	The first essential ingredient for success for a human mission to a NEO is to complete the NEO survey to identify the most interesting human-accessible targets. A space-based IR survey telescope in a heliocentric orbit ~0.65 to 0.72 Astronomical Units (AU) from the Sun will enable mapping of the remaining NEOs not visible from Earth-based observatories and identification of the orbital dynamic characteristics.
Soil Moisture using L-band GPS	Use the earth-surface "bounced" L-band GPS signal to measure changes in soil moisture with time to improve crop yields and climate models that utilize soil moisture.
Ocean wind speed measurement	Deploy small GPS bistatic receivers on commercial cargo aircraft to utilize ocean-reflected ("bounced") GPS signals for ocean wind speed measurement. Since GPS is available globally, high-resolution wind speed measurements can be taken over large portions of the ocean to study detailed weather patterns and storm development.

8.1 Remote Sensing Instruments/Sensors



Technology Area 8.2 Observatory

Major challenges include:

- X-ray Grazing Incidence Mirror Systems
- UV-Vis-IR Normal Incidence Mirror Systems
- Large Ultra-stable Structures
- Large Deployable/Assembled Structures
- Control of Large Structures
- Distributed Aperture / Formation flying

Technologies support 3 applications:

- X-ray astronomy,
- UVOIR astronomy, and
- Radio / microwave antenna.

Most important metric for all observatories is cost per square meter of aperture.

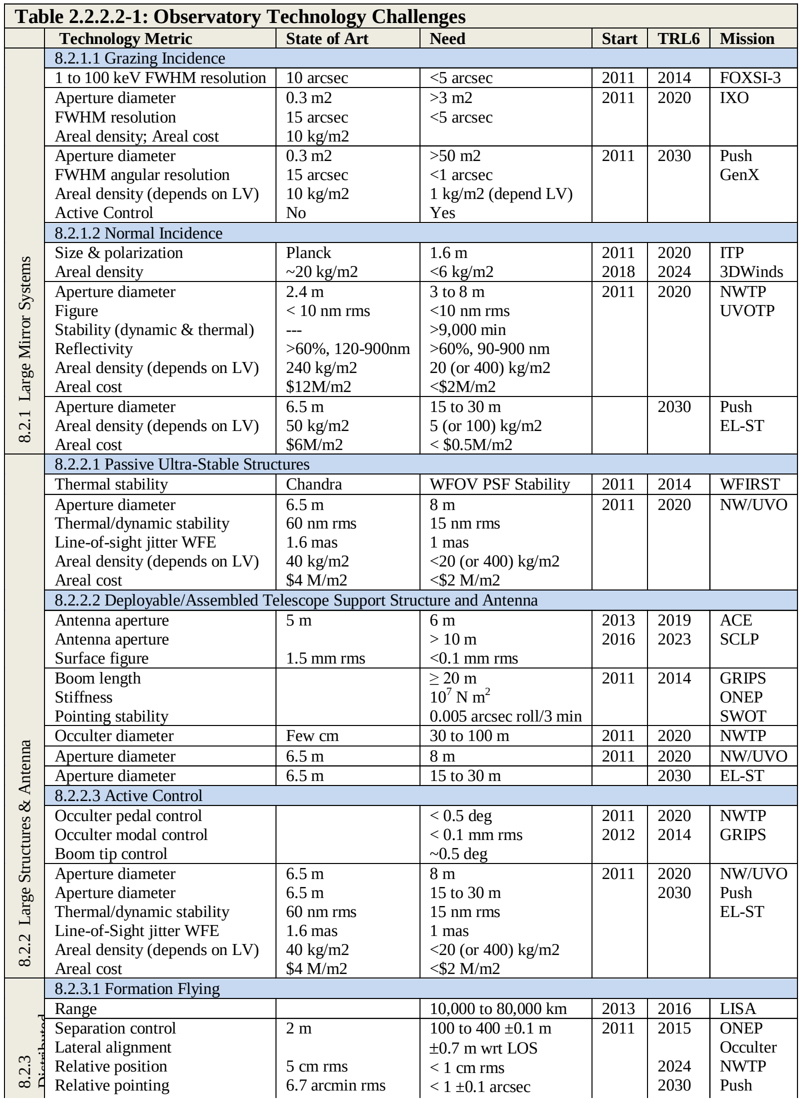


Table 2.2.2.2-1: Observatory Technology Challenges

	Technology Metric	**State of Art**	**Need**	**Start**	**TRL6**	**Mission**
8.2.1 Large Mirror Systems	8.2.1.1 Grazing Incidence					
	1 to 100 keV FWHM resolution	10 arcsec	<5 arcsec	2011	2014	FOXSI-3
	Aperture diameter FWHM resolution Areal density; Areal cost	0.3 m2 15 arcsec 10 kg/m2	>3 m2 <5 arcsec	2011	2020	IXO
	Aperture diameter FWHM angular resolution Areal density (depends on LV) Active Control	0.3 m2 15 arcsec 10 kg/m2 No	>50 m2 <1 arcsec 1 kg/m2 (depend LV) Yes	2011	2030	Push GenX
	8.2.1.2 Normal Incidence					
	Size & polarization Areal density	Planck ~20 kg/m2	1.6 m <6 kg/m2	2011 2018	2020 2024	ITP 3DWinds
	Aperture diameter Figure Stability (dynamic & thermal) Reflectivity Areal density (depends on LV) Areal cost	2.4 m < 10 nm rms --- >60%, 120-900nm 240 kg/m2 $12M/m2	3 to 8 m <10 nm rms >9,000 min >60%, 90-900 nm 20 (or 400) kg/m2 <$2M/m2	2011	2020	NWTP UVOTP
	Aperture diameter Areal density (depends on LV) Areal cost	6.5 m 50 kg/m2 $6M/m2	15 to 30 m 5 (or 100) kg/m2 < $0.5M/m2		2030	Push EL-ST
8.2.2 Large Structures & Antenna	8.2.2.1 Passive Ultra-Stable Structures					
	Thermal stability	Chandra	WFOV PSF Stability	2011	2014	WFIRST
	Aperture diameter Thermal/dynamic stability Line-of-sight jitter WFE Areal density (depends on LV) Areal cost	6.5 m 60 nm rms 1.6 mas 40 kg/m2 $4 M/m2	8 m 15 nm rms 1 mas <20 (or 400) kg/m2 <$2 M/m2	2011	2020	NW/UVO
	8.2.2.2 Deployable/Assembled Telescope Support Structure and Antenna					
	Antenna aperture Antenna aperture Surface figure	5 m 1.5 mm rms	6 m > 10 m <0.1 mm rms	2013 2016	2019 2023	ACE SCLP
	Boom length Stiffness Pointing stability		≥ 20 m 10^7 N m^2 0.005 arcsec roll/3 min	2011	2014	GRIPS ONEP SWOT
	Occulter diameter	Few cm	30 to 100 m	2011	2020	NWTP
	Aperture diameter	6.5 m	8 m	2011	2020	NW/UVO
	Aperture diameter	6.5 m	15 to 30 m		2030	EL-ST
	8.2.2.3 Active Control					
	Occulter pedal control Occulter modal control Boom tip control		< 0.5 deg < 0.1 mm rms ~0.5 deg	2011 2012	2020 2014	NWTP GRIPS
	Aperture diameter Aperture diameter Thermal/dynamic stability Line-of-Sight jitter WFE Areal density (depends on LV) Areal cost	6.5 m 6.5 m 60 nm rms 1.6 mas 40 kg/m2 $4 M/m2	8 m 15 to 30 m 15 nm rms 1 mas <20 (or 400) kg/m2 <$2 M/m2	2011	2020 2030	NW/UVO Push EL-ST
8.2.3	8.2.3.1 Formation Flying					
	Range		10,000 to 80,000 km	2013	2016	LISA
	Separation control Lateral alignment Relative position Relative pointing	2 m 5 cm rms 6.7 arcmin rms	100 to 400 ±0.1 m ±0.7 m wrt LOS < 1 cm rms < 1 ±0.1 arcsec	2011	2015 2024 2030	ONEP Occulter NWTP Push

Table 2.2.2.2-1: Observatory Technology Challenges

	Technology Metric	State of Art	Need	Start	TRL6	Mission
8.2.1 Large Mirror Systems	8.2.1.1 Grazing Incidence					
	1 to 100 keV FWHM resolution	10 arcsec	<5 arcsec	2011	2014	FOXSI-3
	Aperture diameter	0.3 m2	>3 m2	2011	2020	IXO
	FWHM resolution	15 arcsec	<5 arcsec			
	Areal density; Areal cost	10 kg/m2				
	Aperture diameter	0.3 m2	>50 m2	2011	2030	Push
	FWHM angular resolution	15 arcsec	<1 arcsec			GenX
	Areal density (depends on LV)	10 kg/m2	1 kg/m2 (depend LV)			
	Active Control	No	Yes			
	8.2.1.2 Normal Incidence					
	Size & polarization	Planck	1.6 m	2011	2020	ITP
	Areal density	~20 kg/m2	<6 kg/m2	2018	2024	3DWinds
	Aperture diameter	2.4 m	3 to 8 m	2011	2020	NWTP
	Figure	< 10 nm rms	<10 nm rms			UVOTP
	Stability (dynamic & thermal)	---	>9,000 min			
	Reflectivity	>60%, 120-900nm	>60%, 90-900 nm			
	Areal density (depends on LV)	240 kg/m2	20 (or 400) kg/m2			
	Areal cost	$12M/m2	<$2M/m2			
	Aperture diameter	6.5 m	15 to 30 m		2030	Push
	Areal density (depends on LV)	50 kg/m2	5 (or 100) kg/m2			EL-ST
	Areal cost	$6M/m2	< $0.5M/m2			
8.2.2 Large Structures & Antenna	8.2.2.1 Passive Ultra-Stable Structures					
	Thermal stability	Chandra	WFOV PSF Stability	2011	2014	WFIRST
	Aperture diameter	6.5 m	8 m	2011	2020	NW/UVO
	Thermal/dynamic stability	60 nm rms	15 nm rms			
	Line-of-sight jitter WFE	1.6 mas	1 mas			
	Areal density (depends on LV)	40 kg/m2	<20 (or 400) kg/m2			
	Areal cost	$4 M/m2	<$2 M/m2			
	8.2.2.2 Deployable/Assembled Telescope Support Structure and Antenna					
	Antenna aperture	5 m	6 m	2013	2019	ACE
	Antenna aperture		> 10 m	2016	2023	SCLP
	Surface figure	1.5 mm rms	<0.1 mm rms			
	Boom length		≥ 20 m	2011	2014	GRIPS
	Stiffness		10^7 N m^2			ONEP
	Pointing stability		0.005 arcsec roll/3 min			SWOT
	Occulter diameter	Few cm	30 to 100 m	2011	2020	NWTP
	Aperture diameter	6.5 m	8 m	2011	2020	NW/UVO
	Aperture diameter	6.5 m	15 to 30 m		2030	EL-ST
	8.2.2.3 Active Control					
	Occulter pedal control		< 0.5 deg	2011	2020	NWTP
	Occulter modal control		< 0.1 mm rms	2012	2014	GRIPS
	Boom tip control		~0.5 deg			
	Aperture diameter	6.5 m	8 m	2011	2020	NW/UVO
	Aperture diameter	6.5 m	15 to 30 m		2030	Push
	Thermal/dynamic stability	60 nm rms	15 nm rms			EL-ST
	Line-of-Sight jitter WFE	1.6 mas	1 mas			
	Areal density (depends on LV)	40 kg/m2	<20 (or 400) kg/m2			
	Areal cost	$4 M/m2	<$2 M/m2			
8.2.3 Distributed	8.2.3.1 Formation Flying					
	Range		10,000 to 80,000 km	2013	2016	LISA
	Separation control	2 m	100 to 400 ±0.1 m	2011	2015	ONEP
	Lateral alignment		±0.7 m wrt LOS			Occulter
	Relative position	5 cm rms	< 1 cm rms		2024	NWTP
	Relative pointing	6.7 arcmin rms	< 1 ±0.1 arcsec		2030	Push

Observatory Budget Recommendations

$400M over 10-yrs to Industry/Academia for X-Ray mirrors, large UV mirrors, large structures, and formation flying:

Program	10 year	2012	2021
IXO	$150M	$3M/yr	$20M/yr
New World	$100M	$2M/yr	$15M/yr
UVO	$ 20M	$1M/yr	$5M/yr
General	$100M	$10M/yr	$10M/yr
Earth/Helio	$ 30M	$1M/yr	$5M/yr
TOTAL	$400M	$17M/yr	$55M/yr

Plus another $200M over 10-years for Internal NASA funding

75 FTE/yr & $5M/yr ODC

Table 2.2.2.2-1: Observatory Technology Challenges

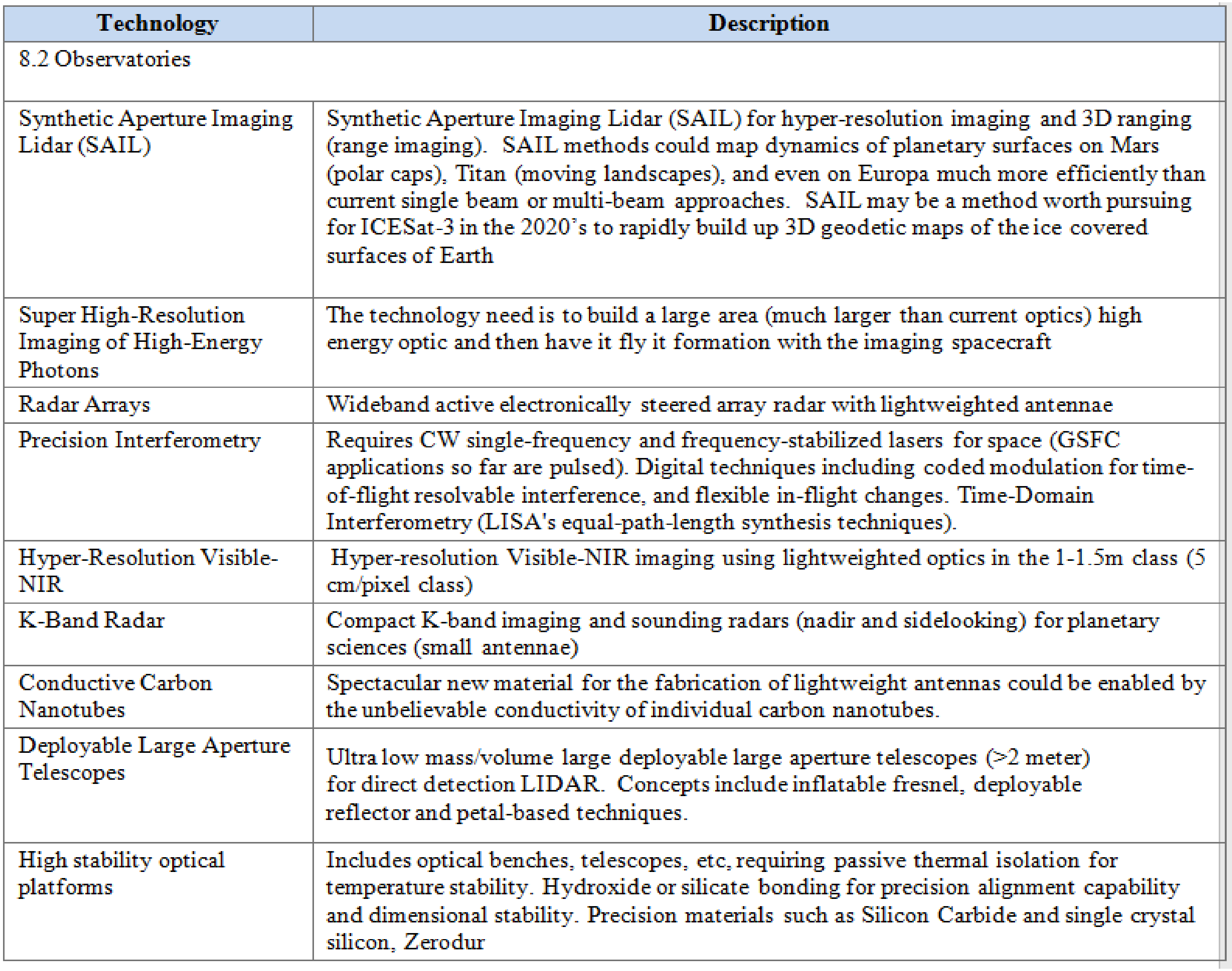
	Technology Metric	State of Art	Need	TRL	TRL6	Mission	10-yr External			NASA Internal	
							Total	FY12	FY21	FTE/yr	ODC/yr
	8.2 Observatory Technology						**$400M**	**$19M**	**$48M**	**75/yr**	**$5M/yr**
8.2.1 Large Mirror Systems	8.2.1.1 Grazing Incidence						$170M	$6M	$22M	30	$2M
	1 to 100 keV FWHM resolution	10 arcsec	<5 arcsec	5	2014	FOXSI-3	5	2	-	6	.5
	Aperture diameter FWHM resolution Areal density; Areal cost	0.3 m2 15 arcsec 10 kg/m2	>3 m2 <5 arcsec	3	2020	IXO	150	3	20	22	1.5
	Aperture diameter FWHM angular resolution Areal density (depends LV) Active Control	0.3 m2 15 arcsec 10 kg/m2 No	>50 m2 <1 arcsec 1 kg/m2 (depend LV) Yes	2	2030	Push GenX	15	1	2	2	-
	8.2.1.2 Normal Incidence						$80M	$3M	$8M	15	$1M
	Size & polarization Areal density	Planck ~20 kg/m2	1.6 m <6 kg/m2	5 5	2020 2024	ITP 3DWinds	5	1	-	3	-
	Aperture diameter Figure Stability (dynamic & thermal) Reflectivity Areal density (depends LV) Areal cost	2.4 m < 10 nm rms --- >60%, 120-900nm 240 kg/m2 $12M/m2	3 to 8 m <10 nm rms >9,000 min >60%, 90-900 nm 20 (or 400) kg/m2 <$2M/m2	4	2020	NWTP UVOTP	75	2	9	10	1
	Aperture diameter Areal density (depends LV) Areal cost	6.5 m 50 kg/m2 $6M/m2	15 to 30 m 5 (or 100) kg/m2 < $0.5M/m2	2	2030	Push EL-ST	TBD	TBD	TBD	2	-
8.2.2 Large Structures & Antenna	8.2.2.1 Passive Ultra-Stable Structures						$20M	$3M	$2M	4	$0.3M
	Thermal stability	Chandra	WFOV PSF Stability	5	2014	WFIRST	5	2	-	2	-
	Aperture diameter Thermal/dynamic stability Line-of-sight jitter WFE Areal density (depends LV) Areal cost	6.5 m 60 nm rms 1.6 mas 40 kg/m2 $4 M/m2	8 m 15 nm rms 1 mas <20 (or 400) kg/m2 <$2 M/m2	3	2020	NW/UVO	15	1	2	2	.3
	8.2.2.2 Deployable/Assembled Telescope Support Structure and Antenna						$50M	$4M	$6M	10	$0.7M
	Antenna aperture Antenna aperture Surface figure	5 m 1.5 mm rms	6 m > 10 m <0.1 mm rms	5 3	2019 2023	ACE SCLP	5	1	-	1	-
	Boom length Stiffness Pointing stability		≥ 20 m 10^7 N m^2 0.005 arcsec roll/3 min	5	2014	GRIPS ONEP SWOT	5	2	-	3	.3
	Occulter diameter	Few cm	30 to 100 m	2	2020	NWTP	20	1	3	3	.3
	Aperture diameter	6.5 m	8 m	4	2020	NW/UVO	20	1	3	2	.1
	Aperture diameter	6.5 m	15 to 30 m	2	2030	EL-ST	TBD	TBD	TBD	1	-
	8.2.2.3 Active Control						$30M	$2M	$4M	6	$0.4M
	Occulter pedal control Occulter modal control Boom tip control		< 0.5 deg < 0.1 mm rms ~0.5 deg	3 5	2020 2014	NWTP GRIPS	15	1	2	3	.2
	Aperture diameter Aperture diameter Thermal/dynamic stability Line-of-Sight jitter WFE Areal density (depends LV) Areal cost	6.5 m 6.5 m 60 nm rms 1.6 mas 40 kg/m2 $4 M/m2	8 m 15 to 30 m 15 nm rms 1 mas <20 (or 400) kg/m2 <$2 M/m2	3 2	2020 2030	NW/UVO Push EL-ST	15	1	2	3	.2
8.2.3 Distributed	8.2.3.1 Formation Flying						$50M	$1M	$7M	10	$0.6M
	Range		10,000 to 80,000 km	5	2016	LISA	TBD	TBD	TBD	1	-
	Separation control Lateral alignment Relative position Relative pointing	2 m 5 cm rms 6.7 arcmin rms	100 to 400 ±0.1 m ±0.7 m wrt LOS < 1 cm rms < 1 ±0.1 arcsec	5 3 2	2015 2024 2030	ONEP Occulter NWTP Push	50	1	7	9	.6

Table 2.2.2.2-1: Observatory Technology Challenges

	Technology Metric	State of Art	Need	TRL	TRL6	Mission	10-yr External			NASA Internal	
							Total	FY12	FY21	FTE/yr	ODC/yr
	8.2 Observatory Technology						**$400M**	**$19M**	**$48M**	**75/yr**	**$5M/yr**
8.2.1 Large Mirror Systems	8.2.1.1 Grazing Incidence						$170M	$6M	$22M	30	$2M
	1 to 100 keV FWHM resolution	10 arcsec	<5 arcsec	5	2014	FOXSI-3	5	2	-	6	.5
	Aperture diameter FWHM resolution Areal density; Areal cost	0.3 m2 15 arcsec 10 kg/m2	>3 m2 <5 arcsec	3	2020	IXO	150	3	20	22	1.5
	Aperture diameter FWHM angular resolution Areal density (depends LV) Active Control	0.3 m2 15 arcsec 10 kg/m2 No	>50 m2 <1 arcsec 1 kg/m2 (depend LV) Yes	2	2030	Push GenX	15	1	2	2	-
	8.2.1.2 Normal Incidence						$80M	$3M	$8M	15	$1M
	Size & polarization Areal density	Planck ~20 kg/m2	1.6 m <6 kg/m2	5 5	2020 2024	ITP 3DWinds	5	1	-	3	-
	Aperture diameter Figure Stability (dynamic & thermal) Reflectivity Areal density (depends LV) Areal cost	2.4 m < 10 nm rms --- >60%, 120-900nm 240 kg/m2 $12M/m2	3 to 8 m <10 nm rms >9,000 min >60%, 90-900 nm 20 (or 400) kg/m2 <$2M/m2	4	2020	NWTP UVOTP	75	2	9	10	1
	Aperture diameter Areal density (depends LV) Areal cost	6.5 m 50 kg/m2 $6M/m2	15 to 30 m 5 (or 100) kg/m2 < $0.5M/m2	2	2030	Push EL-ST	TBD	TBD	TBD	2	-

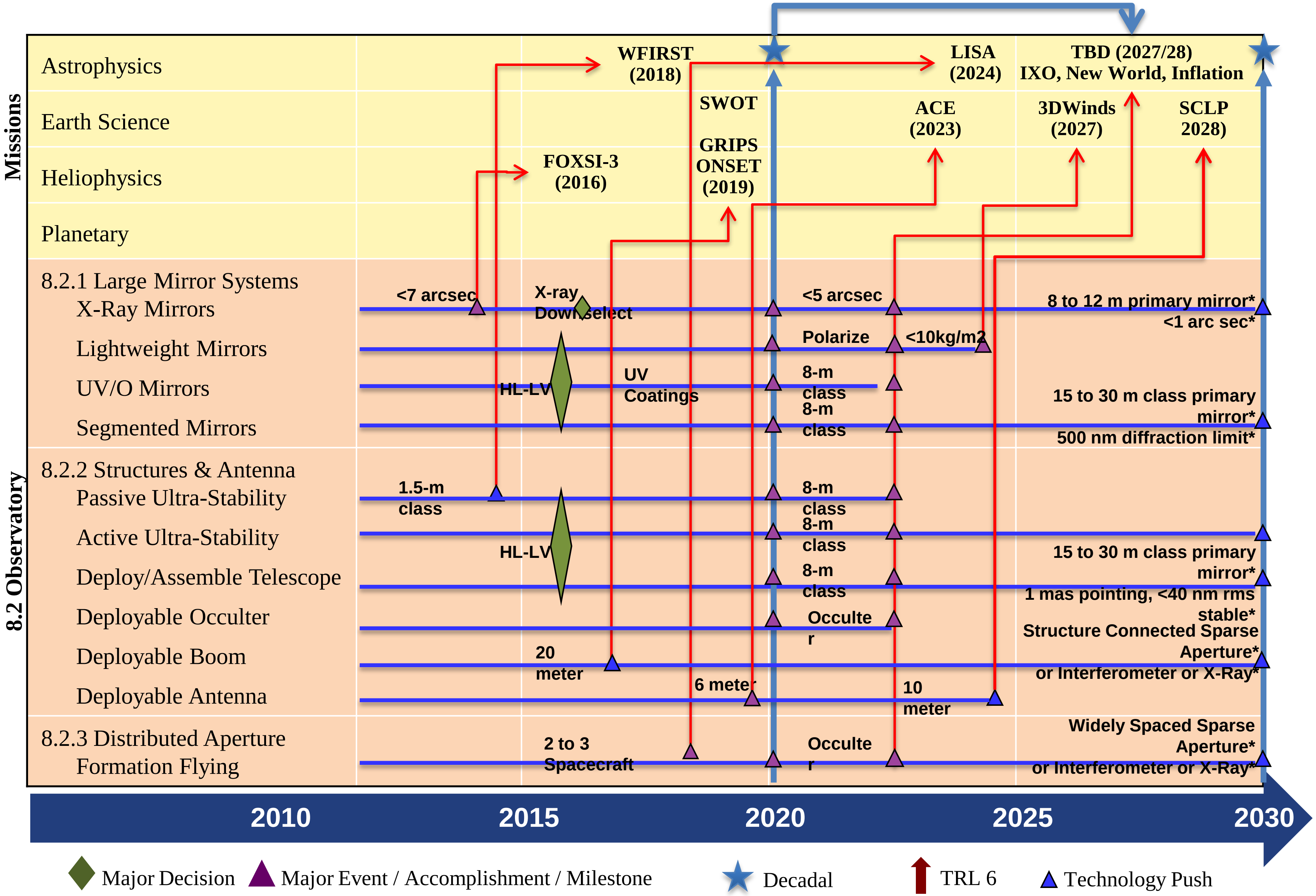
8.2.2 Large Structures & Antenna	8.2.2.1 Passive Ultra-Stable Structures						$20M	$3M	$2M	4	$0.3M
	Thermal stability	Chandra	WFOV PSF Stability	5	2014	WFIRST	5	2	-	2	-
	Aperture diameter Thermal/dynamic stability Line-of-sight jitter WFE Areal density (depends LV) Areal cost	6.5 m 60 nm rms 1.6 mas 40 kg/m2 $4 M/m2	8 m 15 nm rms 1 mas <20 (or 400) kg/m2 <$2 M/m2	3	2020	NW/UVO	15	1	2	2	.3
	8.2.2.2 Deployable/Assembled Telescope Support Structure and Antenna						$50M	$4M	$6M	10	$0.7M
	Antenna aperture Antenna aperture Surface figure	5 m 1.5 mm rms	6 m > 10 m <0.1 mm rms	5 3	2019 2023	ACE SCLP	5	1	-	1	-
	Boom length Stiffness Pointing stability		≥ 20 m 10^7 N m^2 0.005 arcsec roll/3 min	5	2014	GRIPS ONEP SWOT	5	2	-	3	.3
	Occulter diameter	Few cm	30 to 100 m	2	2020	NWTP	20	1	3	3	.3
	Aperture diameter	6.5 m	8 m	4	2020	NW/UVO	20	1	3	2	.1
	Aperture diameter	6.5 m	15 to 30 m	2	2030	EL-ST	TBD	TBD	TBD	1	-
	8.2.2.3 Active Control						$30M	$2M	$4M	6	$0.4M
	Occulter pedal control Occulter modal control Boom tip control		< 0.5 deg < 0.1 mm rms ~0.5 deg	3 5	2020 2014	NWTP GRIPS	15	1	2	3	.2
	Aperture diameter Aperture diameter Thermal/dynamic stability Line-of-Sight jitter WFE Areal density (depends LV) Areal cost	6.5 m 6.5 m 60 nm rms 1.6 mas 40 kg/m2 $4 M/m2	8 m 15 to 30 m 15 nm rms 1 mas <20 (or 400) kg/m2 <$2 M/m2	3 2	2020 2030	NW/UVO Push EL-ST	15	1	2	3	.2
8.2.3 Distributed	8.2.3.1 Formation Flying						$50M	$1M	$7M	10	$0.6M
	Range		10,000 to 80,000 km	5	2016	LISA	TBD	TBD	TBD	1	-
	Separation control Lateral alignment Relative position Relative pointing	2 m 5 cm rms 6.7 arcmin rms	100 to 400 ±0.1 m ±0.7 m wrt LOS < 1 cm rms < 1 ±0.1 arcsec	5 3 2	2015 2024 2030	ONEP Occulter NWTP Push	50	1	7	9	.6

Push Technologies: 8.2 Observatories



Technology	Description
8.2 Observatories	
Synthetic Aperture Imaging Lidar (SAIL)	Synthetic Aperture Imaging Lidar (SAIL) for hyper-resolution imaging and 3D ranging (range imaging). SAIL methods could map dynamics of planetary surfaces on Mars (polar caps), Titan (moving landscapes), and even on Europa much more efficiently than current single beam or multi-beam approaches. SAIL may be a method worth pursuing for ICESat-3 in the 2020's to rapidly build up 3D geodetic maps of the ice covered surfaces of Earth
Super High-Resolution Imaging of High-Energy Photons	The technology need is to build a large area (much larger than current optics) high energy optic and then have it fly it formation with the imaging spacecraft
Radar Arrays	Wideband active electronically steered array radar with lightweighted antennae
Precision Interferometry	Requires CW single-frequency and frequency-stabilized lasers for space (GSFC applications so far are pulsed). Digital techniques including coded modulation for time-of-flight resolvable interference, and flexible in-flight changes. Time-Domain Interferometry (LISA's equal-path-length synthesis techniques).
Hyper-Resolution Visible-NIR	Hyper-resolution Visible-NIR imaging using lightweighted optics in the 1-1.5m class (5 cm/pixel class)
K-Band Radar	Compact K-band imaging and sounding radars (nadir and sidelooking) for planetary sciences (small antennae)
Conductive Carbon Nanotubes	Spectacular new material for the fabrication of lightweight antennas could be enabled by the unbelievable conductivity of individual carbon nanotubes.
Deployable Large Aperture Telescopes	Ultra low mass/volume large deployable large aperture telescopes (>2 meter) for direct detection LIDAR. Concepts include inflatable fresnel, deployable reflector and petal-based techniques.
High stability optical platforms	Includes optical benches, telescopes, etc, requiring passive thermal isolation for temperature stability. Hydroxide or silicate bonding for precision alignment capability and dimensional stability. Precision materials such as Silicon Carbide and single crystal silicon, Zerodur

8.2 Observatories Roadmap



Missions

Astrophysics

Earth Science

Heliophysics

Planetary

WFIRST (2018)

SWOT

GRIPS ONSET (2019)

FOXSI-3 (2016)

LISA (2024)

ACE (2023)

3DWinds (2027)

TBD (2027/28) IXO, New World, Inflation

SCLP 2028)

8.2 Observatory

8.2.1 Large Mirror Systems

X-Ray Mirrors

Lightweight Mirrors

UV/O Mirrors

Segmented Mirrors

8.2.2 Structures & Antenna

Passive Ultra-Stability

Active Ultra-Stability

Deploy/Assemble Telescope

Deployable Occulter

Deployable Boom

Deployable Antenna

8.2.3 Distributed Aperture

Formation Flying

<7 arcsec

X-ray Downselect

<5 arcsec

8 to 12 m primary mirror*

<1 arc sec*

Polarize

<10kg/m2

HL-LV

UV Coatings

8-m class

8-m class

15 to 30 m class primary mirror*

500 nm diffraction limit*

1.5-m class

8-m class

8-m class

HL-LV

8-m class

15 to 30 m class primary mirror*

1 mas pointing, <40 nm rms stable*

Occulter

Structure Connected Sparse Aperture*

or Interferometer or X-Ray*

20 meter

6 meter

10 meter

2 to 3 Spacecraft

Occulter

Widely Spaced Sparse Aperture*

or Interferometer or X-Ray*

2010

2015

2020

2025

2030

Major Decision

Major Event / Accomplishment / Milestone

Decadal

TRL 6

Technology Push

Observatory Technology Needs

Regardless of whether the incumbent is 0.5 m or 5 m, the driving need is larger aperture with similar or better performance.

The technologies for achieving performance are

- the ability to manufacture and test large-mirror systems;
- the structure's ability to hold the mirror in a stable, strain-free state under the influence of anticipated dynamic and thermal stimuli; and,
- for extra-large apertures, a method to create the aperture via deployment, assembly, or formation flying – where formation-flying technology is simply an actively controlled virtual structure.

One non-telescope application is the manufacture, deployment, in-plane and formation-flying control of an external-occulting starshade to block starlight for exo-planet observation.

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.

Technology Area 8.3 Sensor Systems

Major challenges include:

Particle and Plasma Sensors

- Energetic Particle Detectors (>30 keV – N MeV)
- Plasma Detectors (<1 eV – 30 keV)
- Magnetometers (DC & AC)

Fields and Waves Sensors

- EM Field Sensors (DC & AC)
- Gravity-Wave Sensors

In-Situ Sensors

- Sample Handling, Preparation, and Containment
- Chemical and Mineral Assessment (Beyond APXS)
- Organic Assessment (Beyond INMS)
- Biological Detection & Characterization
- Planetary Protection (PP)

Techniques for acquiring, processing, transferring, delivering, and storing subsurface samples are critical and represent a huge gap between needed and available *in-situ* sensor technologies

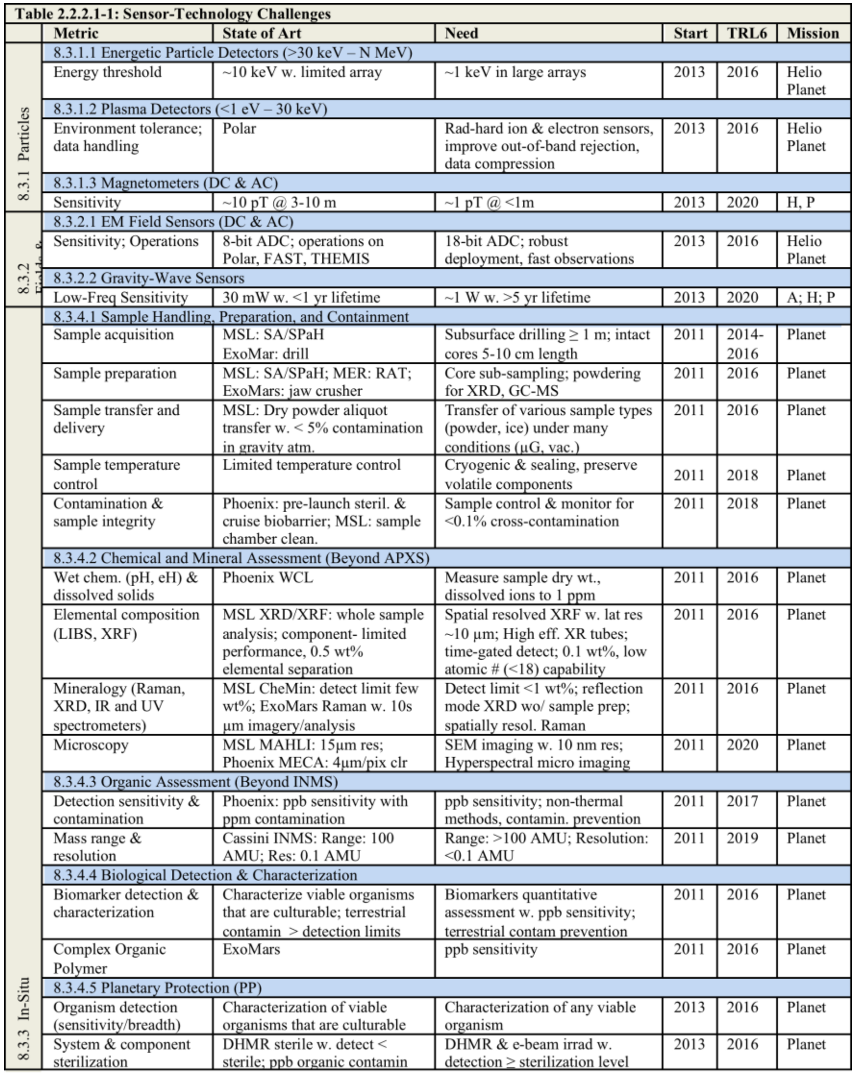
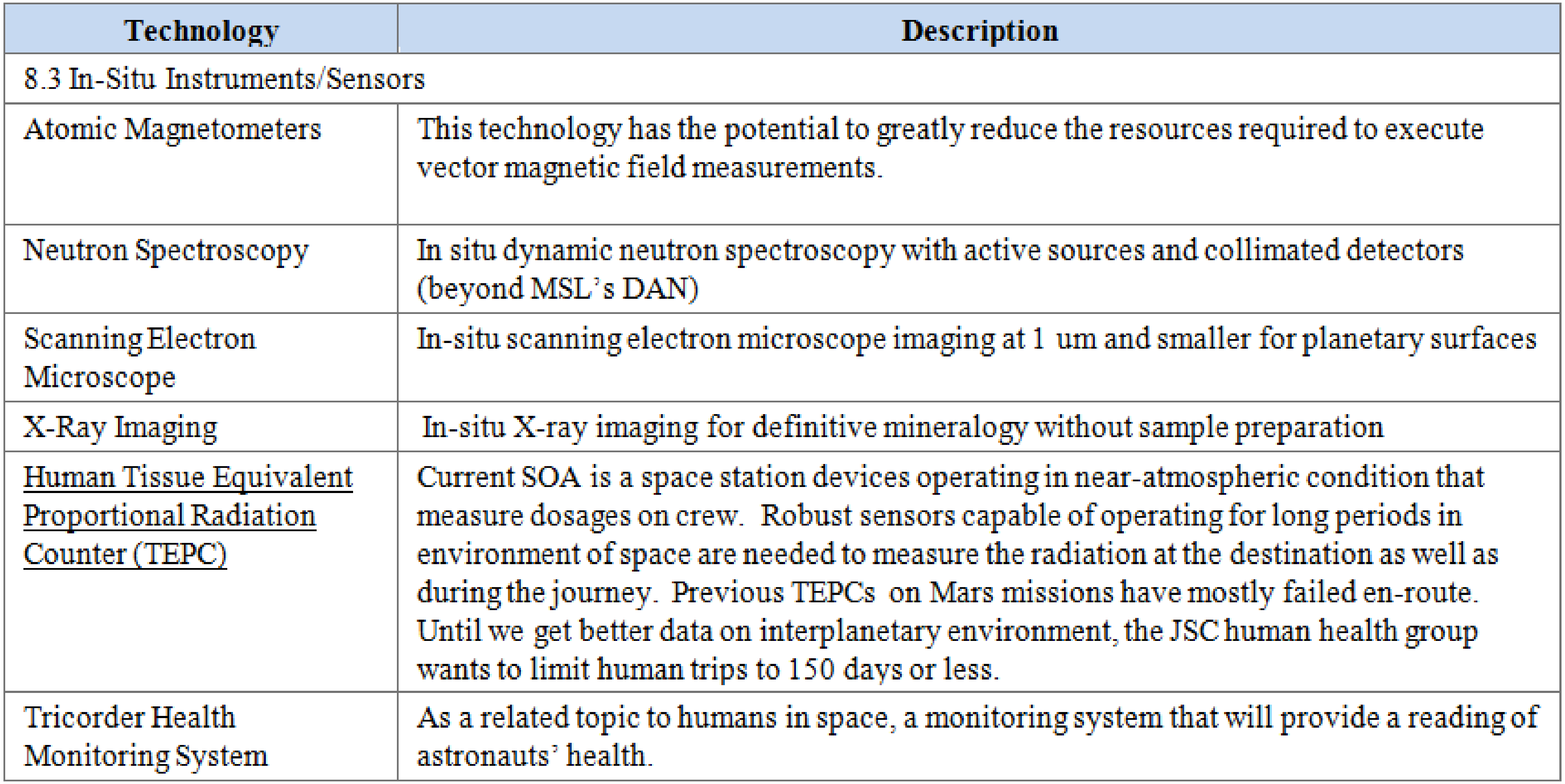


Table 2.2.2.1-1: Sensor-Technology Challenges

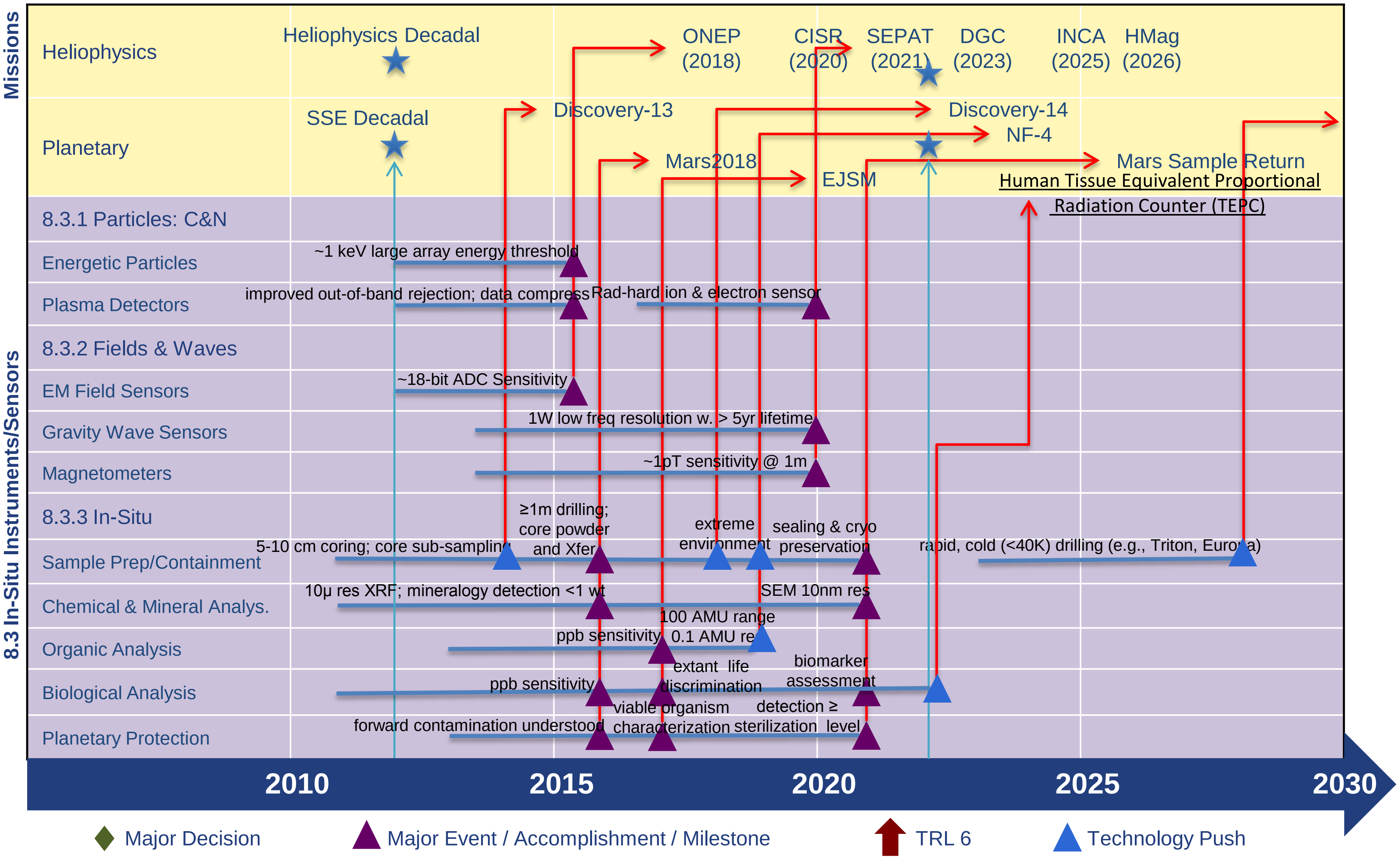
	Metric	**State of Art**	**Need**	**Start**	**TRL6**	**Mission**
8.3.1 Particles	8.3.1.1 Energetic Particle Detectors (>30 keV – N MeV)					
	Energy threshold	~10 keV w. limited array	~1 keV in large arrays	2013	2016	Helio Planet
	8.3.1.2 Plasma Detectors (<1 eV – 30 keV)					
	Environment tolerance; data handling	Polar	Rad-hard ion & electron sensors, improve out-of-band rejection, data compression	2013	2016	Helio Planet
	8.3.1.3 Magnetometers (DC & AC)					
	Sensitivity	~10 pT @ 3-10 m	~1 pT @ <1m	2013	2020	H, P
8.3.2	8.3.2.1 EM Field Sensors (DC & AC)					
	Sensitivity; Operations	8-bit ADC; operations on Polar, FAST, THEMIS	18-bit ADC; robust deployment, fast observations	2013	2016	Helio Planet
	8.3.2.2 Gravity-Wave Sensors					
	Low-Freq Sensitivity	30 mW w. <1 yr lifetime	~1 W w. >5 yr lifetime	2013	2020	A; H; P
8.3.3 In-Situ	8.3.4.1 Sample Handling, Preparation, and Containment					
	Sample acquisition	MSL: SA/SPaH ExoMar: drill	Subsurface drilling ≥ 1 m; intact cores 5-10 cm length	2011	2014-2016	Planet
	Sample preparation	MSL: SA/SPaH; MER: RAT; ExoMars: jaw crusher	Core sub-sampling; powdering for XRD, GC-MS	2011	2016	Planet
	Sample transfer and delivery	MSL: Dry powder aliquot transfer w. < 5% contamination in gravity atm.	Transfer of various sample types (powder, ice) under many conditions (µG, vac.)	2011	2016	Planet
	Sample temperature control	Limited temperature control	Cryogenic & sealing, preserve volatile components	2011	2018	Planet
	Contamination & sample integrity	Phoenix: pre-launch steril. & cruise biobarrier; MSL: sample chamber clean.	Sample control & monitor for <0.1% cross-contamination	2011	2018	Planet
	8.3.4.2 Chemical and Mineral Assessment (Beyond APXS)					
	Wet chem. (pH, eH) & dissolved solids	Phoenix WCL	Measure sample dry wt., dissolved ions to 1 ppm	2011	2016	Planet
	Elemental composition (LIBS, XRF)	MSL XRD/XRF: whole sample analysis; component- limited performance, 0.5 wt% elemental separation	Spatial resolved XRF w. lat res ~10 µm; High eff. XR tubes; time-gated detect; 0.1 wt%, low atomic # (<18) capability	2011	2016	Planet
	Mineralogy (Raman, XRD, IR and UV spectrometers)	MSL CheMin: detect limit few wt%; ExoMars Raman w. 10s µm imagery/analysis	Detect limit <1 wt%; reflection mode XRD wo/ sample prep; spatially resol. Raman	2011	2016	Planet
	Microscopy	MSL MAHLI: 15µm res; Phoenix MECA: 4µm/pix clr	SEM imaging w. 10 nm res; Hyperspectral micro imaging	2011	2020	Planet
	8.3.4.3 Organic Assessment (Beyond INMS)					
	Detection sensitivity & contamination	Phoenix: ppb sensitivity with ppm contamination	ppb sensitivity; non-thermal methods, contamin. prevention	2011	2017	Planet
	Mass range & resolution	Cassini INMS: Range: 100 AMU; Res: 0.1 AMU	Range: >100 AMU; Resolution: <0.1 AMU	2011	2019	Planet
	8.3.4.4 Biological Detection & Characterization					
	Biomarker detection & characterization	Characterize viable organisms that are culturable; terrestrial contamin > detection limits	Biomarkers quantitative assessment w. ppb sensitivity; terrestrial contam prevention	2011	2016	Planet
	Complex Organic Polymer	ExoMars	ppb sensitivity	2011	2016	Planet
	8.3.4.5 Planetary Protection (PP)					
	Organism detection (sensitivity/breadth)	Characterization of viable organisms that are culturable	Characterization of any viable organism	2013	2016	Planet
	System & component sterilization	DHMR sterile w. detect < sterile; ppb organic contamin	DHMR & e-beam irrad w. detection ≥ sterilization level	2013	2016	Planet

Push Technologies: 8.3 Sensor Systems



Technology	Description
8.3 In-Situ Instruments/Sensors	
Atomic Magnetometers	This technology has the potential to greatly reduce the resources required to execute vector magnetic field measurements.
Neutron Spectroscopy	In situ dynamic neutron spectroscopy with active sources and collimated detectors (beyond MSL’s DAN)
Scanning Electron Microscope	In-situ scanning electron microscope imaging at 1 um and smaller for planetary surfaces
X-Ray Imaging	In-situ X-ray imaging for definitive mineralogy without sample preparation
Human Tissue Equivalent Proportional Radiation Counter (TEPC)	Current SOA is a space station devices operating in near-atmospheric condition that measure dosages on crew. Robust sensors capable of operating for long periods in environment of space are needed to measure the radiation at the destination as well as during the journey. Previous TEPCs on Mars missions have mostly failed en-route. Until we get better data on interplanetary environment, the JSC human health group wants to limit human trips to 150 days or less.
Tricorder Health Monitoring System	As a related topic to humans in space, a monitoring system that will provide a reading of astronauts’ health.

8.3 Sensor Systems



Remote Sensing Instruments/Sensors Public Inputs

Detectors and Focal Planes:

CZT detectors for x-ray or gamma-ray; next-generation solar-blind photo-cathodes; TES detectors; CMB detectors; BGO scintillators; UV photon counting detectors; NIR photon counting detectors; detector with small pixels than specified; detector arrays of size larger than specified; detectors with lower noise than specified.

Electronics:

5 for ASIC; 3 on miniaturizing; & 2 each regarding multiplexers, low-noise amplifiers & gravity wave phase sensor electronics.

Optical Components:

2 for WFSC to correct phase, intensity, amplitude & polarization; 4 for components ranging from x-ray & UV diffraction gratings to narrow band spectral filters to electronically steerable laser beam; 3 microwave polarization feed horns and planar antenna.

3 Radio/Microwave; 1 Lasers and 1 Cryogenic/Thermal.

Public Inputs

Observatory:

8m UVOIR and 4m UVOIR telescopes, 100 meter microwave antenna, high reflectance UV coatings, x-ray and gamma ray imaging optics on 20 meter booms, athermal telescope structures, 400 sq meter microwave phased array antenna structure, 300 meter booms for atom interferometers and distributed aperture systems.

In-Situ Instruments/Sensors:

1 regarding neutral ion detection, 4 regarding atomic clocks, 5 regarding gravity wave detection, 1 for quantum communication, 1 for mineral assessment and 1 other.

Acronyms

ACE — Aerosol/Cloud/Ecosystems
ADC — Analog to Digital Converter
AMU — Atomic Mass Unit
AO — Autonomous Operation
APD —Avalanche Diodes
APIO — Advanced Planning and Integration Office
AR&D — Applied Research and Development
ASCENDS — Active Sensing of CO2 Emissions over Nights, Days, and Seasons
ASIC — Application Specific Integrated Circuit
ATLAST — Advanced Technology Large Aperture Space Telescope
APXS — Alpha Particle X-Ray Spectrometer
AU — Astronomical Units
BEP — Beamed Energy Propulsion
CCD — Charged Coupled Device
CheMin — Chemical Mineral Instrument
CISR — Climate Impacts of Space Radiation
COM — Communications
CW — Continuous Wave
DIAL — Differential Absorption Lidar
DGC — Dynamic Geospace Coupling
DHMR — Dry Heat Microbial Reduction
EDL — Entry, Descent and Landing
EJSM — Europa-Jupiter System *Mission*
ELST — Extremely Large Space Telescopes
EM — Electromagnetic
EMS — Environmental Monitoring and Safety
FAST — Fast Auroral SnapshoT
FOV — Field of View
FOXSI — Focusing Optics X-ray Solar Imager
FPA — Focal Plane Array
FWHM-Full Width Half Maximum
GACM — Global Atmospheric Composition Mission
GC-MS — Gas Chromatography-Mass Spectroscopy
GenX — Generation-X Vision
GEO — Geosynchronous Orbit
GEO-CAPE — Geostationary Coastal and Air Pollution Events
GPS — Global Positioning Satellite
GRACE — Gravity Recovery and Climate Experiment
GRIPS — Gamma-Ray Imager/Polarimeter for Solar
HEDS — Human Exploration Destination Systems
HERO — High-Energy Replicated Optics
HiRISE — High Resolution Imaging Science Experiment
HMaG — Heliospheric Magnetics
HyspIRI — Hyperspectral Infrared Imager
Hz — Hertz
IHM — Integrated Health Management
InGaAs — Indium Gallium Arsenide
INMS — Ion and Neutral Mass Spectrometer
INCA — Ion-Neutral Coupling in the Atmosphere
IXO — International X-ray Observatory
JAXA — Japanese Aerospace and Exploration Agency
LCAS — Low-Cost Access to Space
LIBS — Laser-Induced Breakdown Spectroscopy
LIMA — Long-range laser Induced Mass Analysis
LISA — Laser Interferometer Space Antenna
LIST — Lidar Surface Topography
LROC — Lunar Reconnaissance Orbiter Camera
MAHLI — Mars Hand Lens Imager
MCP — Microchannel Plate
Mdeg — Millidegree
MECA — Microscopy, Electrochemistry, and Conductivity Analyzer
MER — Mars Exploration Rovers
MKIDS — Microwave Kinetic Inductance Detectors
MSL — Mars Science Lab

Acronyms

MSR — Mars Sample Return
NDE — Non-Destructive Evaluation
NEO — Near Earth Object
NEP — Noise Equivalent Power
NF — New Frontiers
NIR — Near Infrared
NRC — National Research Council
NuSTAR — Nuclear Spectroscopic Telescope Array
NW — New Worlds
O — Optical
ONSET — Origins of Near Earth Plasma
OR&PE — Object Recognition and Pose Estimation
PATH — Precipitation and All Weather Temperature and Humidity
PNT — Position, Navigation, and Timing
PRF —Pulse Repetition Frequency
PSF — Point Spread Function
PVP — Photovoltaic Power
QE — Quantum Efficiency
RAT — Rock Abrasion Tool
RFI — Radio Frequency Interference
ROIC — Readout Integrated Circuit
SAIL — Synthetic Aperture Imaging Lidar
SAR — Synthetic Aperture Radar
SA/SPaH — Sample Acquisition / Sample Processing and Handling
SCLP — Snow and Cold Land Processes
SEM — Scanning Electron Microscope
SEM — Space Experiment Module
SEPAT — Solar Energetic Particle Acceleration and Transport
SEU/SEL — Single Event Upset/Single Event Latchup
SIOSS — Science Instruments, Observatories, and Sensor Systems
SMD — Science Mission Directorate
SPICA — Science Investigation Concept Studies
SSE — Solar System Exploration
STP — Solar Thermal Propulsion
SWOT — Surface Water and Ocean Topography
TABS — Technology Area Breakdown Structure
TEPC — Tissue Equivalent Proportional Radiation Counter
TES — Transition Edge Sensors
THEMIS — Time History of Events and Macroscale Interactions during Substorms
THz — TeraHertz
TID — Total Ionizing Dose
TIR —Thermal Infrared
TPF-C — Terrestrial Planet Finder-Coronagraph
TPS — Thermal Protection System
T/R — Transmitter/Receiver
UAV — Unmanned Aerial Vehicle
UV — Ultraviolet
UVOIR — UV-Optical-near IR Telescope
VIS — Visible
WCL — Wet Chemistry Laboratory
WFE — Wall Plug Efficiency
WFOV — Wide Field of View
WFIRST — Wide-Field Infrared Survey Telescope
WFSC — Wavefront Sensing and Control
WINCS — Wind Ion-drift Neutral-ion Composition
WPT — Wireless Power Transmission
XMM — X-ray Multi-Mirror Mission
XRD — X-Ray Diffraction
XRF — X-ray Fluorescence