Science Instruments, Observatories, and Sensor Systems *

*Ref 1: Draft Science Instruments, Observatories, and Sensor System Roadmap, Technology Area 08, NASA, November 2010

Earth and Planetary Remote Sensing Instruments/Sensors

Panelists: Keith Raney (JHU/APL)
Chris Webster (JPL)

*Ref 1: Draft Science Instruments, Observatories, and Sensor System Roadmap, Technology Area 08, NASA, November 2010

National Academies, Beckman Center, 29 March 2011
Our Solar System - a Diversity of Challenges for Remote Sensing Instruments

• The sophisticated needs for Earth science, and the huge diversity of other planetary target bodies presents a myriad of technology challenges for remote and in situ instruments;

• Large variations are encountered in
  - Size, shape, and rotation rate
  - Absolute temperatures
  - Thermal variations
  - Surface compositions and activity
  - Atmospheric densities, cloud cover, gas compositions
  - Solar intensities
  - Radiation environment
  - Planetary protection requirements
  - Magnetic and Gravitational fields

• Flight qualification to high TRL (“relevant environment”) is therefore target body-specific

Panel-5, National Academies, Beckman Center, 29 March 2011
Exploring our Solar System requires a Diversity of Flight Ready Instruments

JPL’s AIRS

GSFC’s SAM

Ball’s HiRISE

NASA-ESA Cassini-Huygens

Panel-5, National Academies, Beckman Center, 29 March 2011
### Typical Remote Sensing (Orbiter) Payloads

**Earth Aura Satellite**
- Scanning IR limb sounder (HIRDLS)
- Microwave limb sounder/radiometer (MLS)
- UV spectrometer for ozone, aerosol (OMI)
- Thermal emission FTIR imaging spectrometer (TES)

**Mars Reconnaissance Orbiter (MRO)**
- Cameras (HiRISE NAC, Context CTX, Color imager MARCI, Opt Nav)
- Vis-NIR imaging spectrometer CRISM
- Mars Climate Sounder MCS thermal imager
- SHARAD Radar sounder
- Atmospheric structure and gravity

**Europa (JEO) Orbiter**
- Ice Penetrating Radar (IPR)
- Vis-IR Spectrometer (VIRIS)
- Wide-Angle (WAC) and Medium-Angle Camera (MAC)
- Narrow Angle Camera (NAC)
- Thermal Instrument (TI)
- Laser Altimeter (LA)
- Ultraviolet Spectrometer (UVS)
- Magnetometer (MAG)
- Radio Science (RS)
- Sub-mm Spectrometer for JGO
- Ion & Neutral Mass Spectrometer (INMS)
- Particle & Plasma Instr. (PPI)

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Panel-5, National Academies, Beckman Center, 29 March 2011
Current NASA Earth Science Missions in Operation

Diagram showing various satellites and space missions orbiting the Earth.
# Earth Science Missions

## Foundation Missions

<table>
<thead>
<tr>
<th>Mission</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Glory—2010</strong></td>
<td>Strategic mission; Initializes a systematic measurement/data continuity. Measure global aerosols and cloud liquid properties and total solar irradiance. Addresses high priority objective of the U.S. Global Change Research Program.</td>
</tr>
<tr>
<td><strong>Aquarius—2011</strong></td>
<td>Competed mission; Earth System Science Pathfinder. Global measurement of sea surface salinity from space; PI-led small Earth science mission. NASA partnership with Argentine space agency.</td>
</tr>
<tr>
<td><strong>NPOESS Preparatory Project—2011</strong></td>
<td>Strategic mission; Systematic measurement/data continuity. Continues several key climate measurements of the Earth Observing System and bridges to JPSS. Joint mission with the NPOESS partners (DOC and DoD); will fill an operational need for JPSS.</td>
</tr>
<tr>
<td><strong>Landsat Data Continuity Mission—2012/13</strong></td>
<td>Strategic mission; Systematic measurement/mandated data continuity. Continues long-term global land cover change data record. Includes thermal infrared sensor. Joint mission with USGS.</td>
</tr>
<tr>
<td><strong>Global Precipitation Measurement—2013</strong></td>
<td>Strategic mission; Initializes a systematic measurement. Extends precipitation measurements spatial coverage to global and temporal coverage to every 3 hours, via a core satellite and a constellation of smaller satellites. NASA partnership with JAXA.</td>
</tr>
</tbody>
</table>

## Tier 1 Missions

- Soil Moisture Active-Passive (SMAP)—2014
- Ice, Cloud and land Elevation Satellite (ICESat-II)—2015
- Climate Absolute Radiance and Refractivity Observatory (CLARREO)—2017 and 2020
- Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI)—2017
- Venture class missions—2017 for first satellite mission. New class of innovative science mission recommended by the decadal survey.

## Tier 2 Missions

- Hyperspectral IR Imager (HyspIRI)
- Active Sensing CO2 (ASCENDS)
- Surface Water & Ocean Topography (SWOT)
- Geostat. Coastal & Air Pollution Events (GEO-CAPE)
- Aerosol-Cloud-Ecosystem (ACE)

## Tier 3 Missions

- Lidar Surface Topography (LIST)
- Precip. Weather, All-Temp Humid. (PATH)
- Grav. Recov. & Climate II (GRACE-II)
- Snow & Cold Land Processes (SCLP)
- Global Atm. Comp. Mapper (GACM)
- 3-D Trop Winds from Space Lidar

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Panel-5, National Academies, Beckman Center, 29 March 2011
Current Planetary Science Missions in Operation

- Deep Impact–EPOXI
- Messenger
- Stardust–NExT
- Cassini (NASA/ESA)
- New Horizons
- Rosetta (ESA)
- Dawn
- Mars Express (ESA/NASA)
- Mars Odyssey
- MRO
- Mars Rovers (Spirit & Opportunity)
# Planetary Science Missions

## Missions in Development

<table>
<thead>
<tr>
<th>Mission Name</th>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mars Science Laboratory</td>
<td>2011</td>
<td>Strategic mission; Mars Exploration Program. Roving analytical laboratory to address questions of habitability. High-priority medium class mission in 2003 decadal survey; developed as a flagship-class mission.</td>
</tr>
<tr>
<td>Gravity Recovery and Interior Laboratory (GRAIL)</td>
<td>2011</td>
<td>Completed mission; Discovery 2006 selection. Generate detailed gravity field maps of the Moon, in the same way as GRACE does now for the Earth, in order to probe the Moon’s interior structure.</td>
</tr>
<tr>
<td>Lunar Atmosphere and Dust Environment Explorer (LADEE)</td>
<td>2012</td>
<td>Strategic mission; Lunar Quest Program. Small mission to study the tenuous atmosphere of the Moon and the dust lofted into the atmosphere.</td>
</tr>
<tr>
<td>Mars Atmosphere and Volatile Evolution (MAVEN)</td>
<td>2013</td>
<td>Completed mission; Mars Exploration Program. Make definitive scientific measurements of present-day atmospheric loss that will offer clues about the history about the Martian atmosphere. High priority science objective of the 2003 decadal survey.</td>
</tr>
</tbody>
</table>

## Future Missions

<table>
<thead>
<tr>
<th>Mission Name</th>
<th>Year</th>
<th>Description</th>
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<tbody>
<tr>
<td>ExoMars Trace Gas Orbiter</td>
<td>2016</td>
<td>Strategic Mission. ESA-led joint mission with NASA; Mars orbiter to follow up on recent methane discovery; entry, descent, landing system (EDLS) tech demo; and telecom package. NASA providing launch, science instruments, and telecom package.</td>
</tr>
<tr>
<td>New Frontiers 3</td>
<td>2018</td>
<td>Completed mission. Three candidates selected for concept studies; asteroid sample return, lunar south pole/Aiken Basin sample return, and Venus atmosphere and surface probe. SMG will select one in 2011 for development.</td>
</tr>
<tr>
<td>Mars 2018</td>
<td>2018</td>
<td>Strategic mission. NASA-led joint mission with ESA. NASA to provide launch, EDLS, rover; ESA to provide a rover/driller. NASA rover to cache samples.</td>
</tr>
<tr>
<td>Europa Jupiter System Mission</td>
<td>early 2020s</td>
<td>Strategic mission. Flagship mission to explore two icy moons of Jupiter. Pursuing as a joint Jupiter System Mission with ESA. NASA spacecraft destination is Europa; ESA’s spacecraft destination is Ganymede.</td>
</tr>
</tbody>
</table>

*From the Planetary Decadal Survey*
Technology Area TA8 Roadmap for Science Instruments, Observatories, and Sensor Systems - Structure Breakdown

8 Science Instruments, Observatories & Sensor Systems (SIOSS)

8.1 Remote Sensing Instruments/Sensors
- 8.1.1 Detectors & Focal Planes
- 8.1.2 Electronics
- 8.1.3 Optical Components
- 8.1.4 Microwave/Radio
- 8.1.5 Lasers
- 8.1.6 Cryogenic/Thermal

8.2 Observatories
- 8.2.1 Mirror Systems
- 8.2.2 Structures & Antenna
- 8.2.3 Distributed Aperture

8.3 In-Situ Instruments/Sensors
- 8.3.1 Particles
- 8.3.2 Fields & Waves
- 8.3.3 In-Situ

After the Draft Science Instruments, Observatories and Sensors Roadmap
TA8.1: Remote Sensing Breakdown Structure

(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
8.1.6.1 Pulsed Lasers
8.1.6.2 Sub-Kelvin Coolers
8.1.6.14-20K Cryo-Coolers for Space

From the Draft Science Instruments, Observatories and Sensors Roadmap
### 8.1 Remote Sensing Instruments/Sensors

#### From the Draft Science Instruments, Observatories and Sensors Roadmap

<table>
<thead>
<tr>
<th>Missions</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
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<tbody>
<tr>
<td>Astrophysics</td>
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<td>Earth Science</td>
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<td>Helophysics</td>
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<td>Planetary</td>
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<tr>
<td>8.1.1 Detectors/ Focal Planes</td>
<td>Large Format Arrays Multi-spectral, 10k x 10k</td>
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<tr>
<td>8.1.2 Electronics</td>
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<tr>
<td>8.1.3 Optical Components</td>
<td>Active Wavefront Control (5nm rms)</td>
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<td>8.1.4 Micro/Radio Trans./Rec.</td>
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<td>8.1.5 Lasers</td>
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<tr>
<td>8.1.6 Cryocoolers</td>
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</table>

**Major Event / Accomplishment / Milestone**
- WFIRST
- ASCENDS
- HyspIRI
- SEPAT
- 3D Winds
- GEOCAPE
- SPICA / IXO
- LIST
- GACM
- EJSM
- DIS 13/14 & NF 4

**Technology Push**
- TRL 6

**Technology**
- 1064, 532, 355nm
- Rad Hard 3 Mrad
- Low Noise (.01%), ROIC (8k x 8k)
- Advanced Spectroscopy Components (1-3 Kg multi-function)
- Integrated radar T/R (10-30W, 60%)
- Low Noise cryogenic mm-Wave Amplifiers
- 1.6 or 2 micron Multi-Freq. Pulsed Laser (Output Energy/Rep rate/ WPE/Laser Lifetime)
- CW laser for gas and fluorescence
- Continuous sub-kelvin cooling

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**Missions**
- NWTP
- EJSM
- WFIRST
- HyspIRI
- SEPAT
- 3D Winds
- GEOCAPE
- SPICA / IXO
- ASCENDS
- DIS 13/14 & NF 4
- GACM

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**Technology**
- Photon Counting
- Large arrays, QE>80%
- ASIC 55krad
- Rad Hard 3Mrad
- Low Noise (.01%), ROIC (8k X 8k)
- Active Wavefront Control (5nm rms)
- Advanced Spectroscopy Components (1-3 Kg multi-function)
- Integrated radar T/R (10-30W, 60%)
- Low Noise cryogenic mm-Wave Amplifiers
- 1.6 or 2 micron Multi-Freq. Pulsed Laser (Output Energy/Rep rate/ WPE/Laser Lifetime)
- CW laser for gas and fluorescence
- Continuous sub-kelvin cooling

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**From the Draft Science Instruments, Observatories and Sensors Roadmap**
Top Technical Challenges Present to 2016

• **In-situ Sensors for Planetary Sample Returns and In-Situ Analysis**
  – Integrated/Miniaturized sensor suites to reduce volume, mass & power; Sub-surface sample gathering to >1 m, intact cores of 10 cm, selective sub-sampling all while preserving potential biological and chemical sample integrity; Unconsolidated material handling in microgravity; Temperature control of frozen samples.

• **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**
  – High power, multi-beam/multi-wavelength, pulsed and continuous wave 0.3-2.0 µm lasers; High efficiency, higher rep rate, longer life lasers.

• **Advanced Microwave Components and Systems**
  – Low-noise amplifiers > 600 GHz, reliable low-power high-speed digital & mixed-signal processing electronics; RFI mitigation for >40 GHz; low-cost scalable radiometer; large (D/λ>8000) deployable antennas; lower-mass receiver, intermediate frequency signal processors, and high-spectral resolution microwave spectrometers.

• **High-Efficiency Coolers**
  – Continuous sub-Kelvin (100% duty cycle) with low vibration, low power (<60W), low cost, low mass, long life

• **In-situ Particle, Field and Wave Sensors**
  – Integrated/Miniaturized sensor suites to reduce volume, mass and power; Improved measurement sensitivity, dynamic range and noise reduction; Radiation hardening; Gravity wave sensor: 5μc/s/√Hz, 1-100mHz

• **Large Focal-Plane Arrays**
  – For all wavelengths (X-Ray, FUV, UV, Visible, NIR, IR, Far-IR), required focal planes with higher QE, lower noise, higher resolution, better uniformity, low power and cost, and 2X to 4X the current pixel counts.

• **Radiation-Hardened Instrument Components**
  – Electronics, detectors, miniaturized instruments; low-noise low-power readout integrated circuits (ROIC); radiation-hardened and miniaturized high-voltage power supplies
Top Technology Challenges **Mid- and Long- Term**

**2017 to 2022 (Mid Term)**
- **High-Contrast Exoplanet Technologies**
  - High-contrast nulling and coronagraphy ($1 \times 10^{-10}$, 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, < $2M/m^2$
  - Enables extra-solar planet detection, general spectroscopy, national defense
- **Atomic Interferometers**
  - Order-of-magnitude improvement in gravity-sensing sensitivity and bandwidths
  - Could enable detection of gravitational waves, more precise earth & planetary gravity mapping, better spacecraft rate sensing

**2023 and Beyond (Long Term)**
- **Sample Handling and Extreme Environment Technologies**
  - Robust, environmentally tolerant robotics, electronics, optics for gathering & processing samples in vacuum, microgravity, radioactive, high or low temperature, high pressure, caustic or corrosive, etc. environments.
- **Spectrometers for Mineralogy**
  - Integrated miniaturized planetary spectrometers to reduce volume, mass and power.
- **Advanced Spatial Interferometric Imaging**
  - Wide field imaging & nulling to spectroscopically image an Earth-twin with >32x32 pixels at 20 parsecs.
- **Many Spacecraft in Formation**
  - Alignment & positioning of 20 to 50 spacecraft distributed over 10s (to 1000s) of kilometers to nanometer precision with milli-arc second pointing knowledge and stability
- **Particle and Field Detectors**
  - Order-of-magnitude increase in sensitivity

*From the Draft Science Instruments, Observatories and Sensors Roadmap*
TA8.1: Remote Sensing Breakdown Structure

**Missing elements: Examples**

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**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.

**Electronics**

8.1.2.1 Radiation Hardened
8.1.2.2 Low Noise
8.1.2.3 High Speed
**NEED? High BW down-link**

**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

**Microwave & Radio Transmitters & Receivers**

8.1.4.1 Integrated Radar T/R Modules
8.1.4.2 Integrated Radiometer Receivers
**NEED? Innovative architectures**
**NEED? Low mass (large) antennas**

**Lasers**

8.1.5.1 Pulsed Lasers
8.1.5.2 CW Lasers

**Cryogenic/Thermal**

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

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*After the Draft Science Instruments, Observatories and Sensors Roadmap*
8.1 Remote Sensing Instruments/Sensors

**Missing dimensions: Examples**

**MISSING:** Incoming arrows from enabling technologies in other roadmap areas (*Examples: large BW comms, lower launch costs*)

**MISSING:** Technology push factors for 8.1.4 (*Examples: rad-hard processors, low-mass large antennas), **8.1.3 & 8.1.5**

**MISSING:** Mitigation plans to *descope* excluded Tier 1 projects (*Example: DESDynI*)

*After the Draft Science Instruments, Observatories and Sensors Roadmap*
Planetary Decadal Survey 2011 Highlights

• **Continue ongoing missions;**
  – Discovery (MESSENGER, Dawn, Kepler, GRAIL
  – New Frontiers: (New Horizons, Juno, NF-3 TBD)
  – Others (Cassini, ODY/MRO/MER, MSL, MAVEN, LADEE, Mars 2016)

• **R&A: Increase the R&A budget over inflation;**

• **Discovery Program**
  – Continue with a regular <24-month cadence of AO’s and selections- no priorities- FY15 cap $0.5B;

• **New Frontiers Program**
  – Continue NF with FY15 cap $1B w/out LV
  – Select NF-4 from Comet Surface Sample Return, Lunar South Pole-Aitken Basin Sample Return, Saturn Probe, Trojan Tour and Rendezvous, Venus In Situ Explorer
  – NF-5 adds Io Observer, Lunar Geophysical Network

• **Flagship Missions**
  – Funds not yet identified, and lower priority than Discovery and NF;
  – Priority: Descoped MAX-C, Descoped JEO, Uranus Orbiter and Probe, Enceladus Orbiter OR Venus Climate Mission

• Continue NASA support for a variety of facilities

• Develop use of Advanced Sterling Radioisotope Generators (ASRG) that require less Pt-238

• **Technology and Instruments**- next slide

*After the Planetary Decadal Survey*
Planetary Decadal Survey 2011 Highlights

**Technology Development**

- A planetary exploration technology development program should be established, and carefully protected from incursions on its resources.

- This program should be funded at 6-8% of the total NASA Planetary Science Division budget.

- High priority mission for future study and technology development:
  - Titan Saturn System Mission,
  - Neptune Orbiter and Probe,
  - Mars Sample Return Lander and Orbiter
Planetary Decadal Survey 2011 Highlights

Technology Development

• A broad-based, sustained program of science instrument technology development should be undertaken to include new instrument concepts as well as improvements of existing instruments.

• This instrument technology program should include the funding of development through TRL-6 for those instruments with the highest potential for making new discoveries.

<table>
<thead>
<tr>
<th>Technology Element</th>
<th>Percentage Allocation</th>
<th>Key Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science instruments</td>
<td>35</td>
<td>Environmental adaptation</td>
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<tr>
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<td>Radiation tolerance</td>
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<td>In situ sample analysis and age dating</td>
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<td>Planetary protection</td>
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<td>Extreme environments</td>
<td>15</td>
<td>High temperature and pressure</td>
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<td>Radiation tolerance (subsystems)</td>
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<td>Cryogenic survival and mobility</td>
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<td>In situ exploration</td>
<td>25</td>
<td>Sample acquisition and handling</td>
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<td>Descent and ascent propulsion systems</td>
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<td>Thermal protection for entry and descent</td>
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<td>Impactor and penetrator systems</td>
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<td>Precision landing</td>
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<td>Mobility on surfaces and in atmospheres</td>
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<td>Planetary protection</td>
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<td>Solar system access and core</td>
<td>25</td>
<td>Reduced spacecraft mass and power</td>
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<tr>
<td>technologies</td>
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<td>Improved interplanetary propulsion</td>
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<td>Low-power, high-rate communications</td>
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<td>Enhanced autonomy and computing</td>
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<td>Aeroeapture</td>
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<td>Improved power sources</td>
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<td>Innovative mission and trajectory design</td>
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<td>Objective: 2023-2032</td>
<td>Mission Architecture</td>
<td>Key Capabilities</td>
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<td><strong>Inner Planets</strong></td>
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<td>Venus climate history</td>
<td>Atmospheric platform</td>
<td>High-temperature survival</td>
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<td>Sample return</td>
<td>Atmospheric mobility</td>
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<td>Advanced chemical propulsion</td>
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<td>Sample handling</td>
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<td>Venus/Mercury interior</td>
<td>Seismic networks</td>
<td>Advanced chemical propulsion</td>
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<td>Long duration high-temperature subsystems</td>
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<td>Lunar volatile inventory</td>
<td>Dark crater rover</td>
<td>Autonomy and mobility</td>
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<td>Cryogenic sampling and instruments</td>
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<td><strong>Mars</strong></td>
<td>Sample return</td>
<td>Ascent propulsion</td>
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<td>Autonomy, precision landing</td>
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<td>In situ instruments</td>
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<td>Planetary protection</td>
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<td><strong>Giant Planets and their Satellites</strong></td>
<td>Coordinated platforms; orbiter, surface and/or lake landers, balloon</td>
<td>Atmospheric mobility</td>
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<td>Remote sensing instruments</td>
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<td>In situ instruments-cryogenic</td>
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<td>Aerocapture</td>
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<td>Uranus and Neptune/Triton</td>
<td>Orbiter, Probe</td>
<td>Advanced power/propulsion</td>
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<td>High-performance telecom</td>
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<td>Thermal protection/entry</td>
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<td><strong>Primitive Bodies</strong></td>
<td>Rendezvous</td>
<td>Advanced power/propulsion</td>
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<tr>
<td>Trojan and KBO composition</td>
<td>Sample return</td>
<td>Advanced thermal protection</td>
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<tr>
<td>Comet/asteroid origin and evolution</td>
<td>Cryogenic sample return</td>
<td>Sampling systems</td>
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<td>Verification of sample—ices, organics</td>
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<td>Cryogenic sample preservation</td>
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<td>Thermal Control during entry, descent, and landing</td>
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</table>

Table 11.1
Affordability

- **Planetary**: The Decadal Survey requires certain programs (especially flagship missions) to be *descoped*, otherwise they cannot be funded

- **Earth observation**: The recent 2012 draft budget and NASA’s response requires major initiatives such as DESDynI to be *descoped*, otherwise they cannot be funded

- **A substantial Descope** necessitates game-changing innovations in technology, architecture, and/or aggressiveness (coverage, data rates and volume, etc) of the mission in question

- **Affordability** is a cross-cutting constraint on technology roadmaps, including remote sensing instruments and missions
Summary & Suggestions

*Instruments, Observatories, & Sensor Technology*

- “A healthy technology R&D program requires three elements: competition, funding, and peer review.” (Ref 1, p. TA08-6)

- Key enabling technologies from outside of the SIOSS roadmap (*e.g.*, affordable and more capable launch vehicles; very wide BW communication; precise formation flying, Ref 1, p. TA08-7) should have more prominence.

- Affordability is a fundamental factor (*most evident in mandatory descopes*).

- Table 1 (Ref 1) should call for game-changing conceptual and architectural innovations in addition to the cited technological advances.

- Table 3 (Ref 1) should include Tier 1 missions not now in NASA’s funding plan.

- Strive to identify Technology Push factors for every one of the 11 pathways (in 6 themes) in the SIOSS Roadmap (Figure 3 in Ref 1).

- Comments and suggestions are invited (in discussion, and in writing) on specific elements of the SIOSS Roadmap that are responsive to the guidelines for this workshop.