Panel-5

Science Instruments, Observatories, and Sensor Systems *

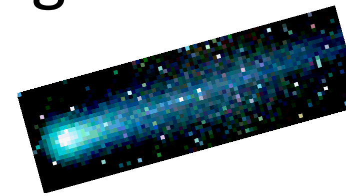
Earth and Planetary Remote Sensing Instruments/Sensors

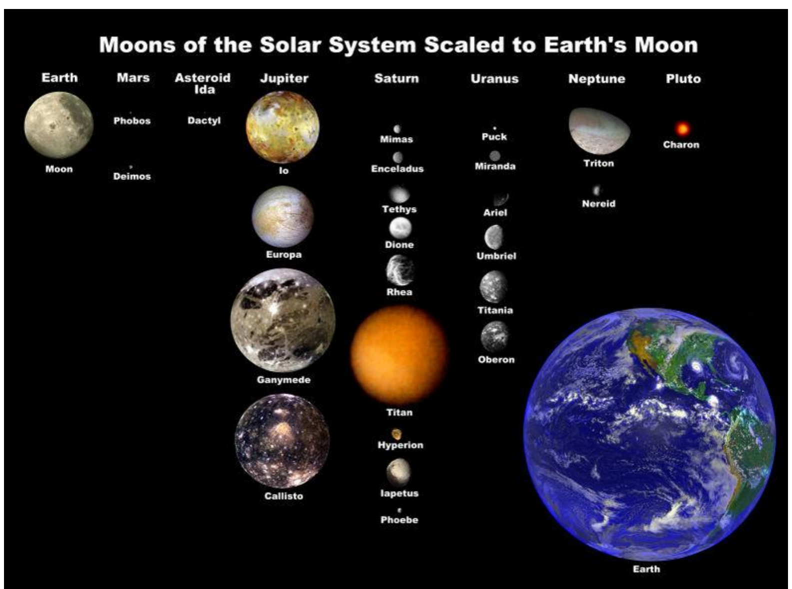
Panelists: Keith Raney (JHU/APL)
Chris Webster (JPL)

**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



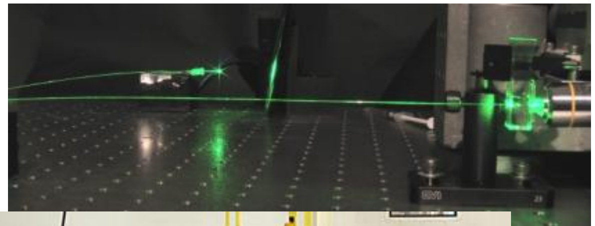


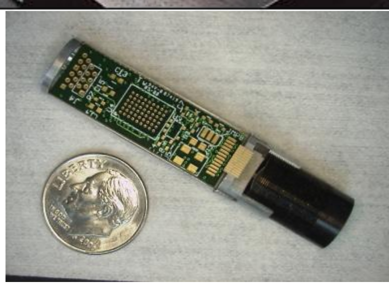
•The **sophisticated needs for Earth science**, and the huge **diversity of other planetary target bodies** presents a myriad of technology challenges for remote and *in situ* instruments;

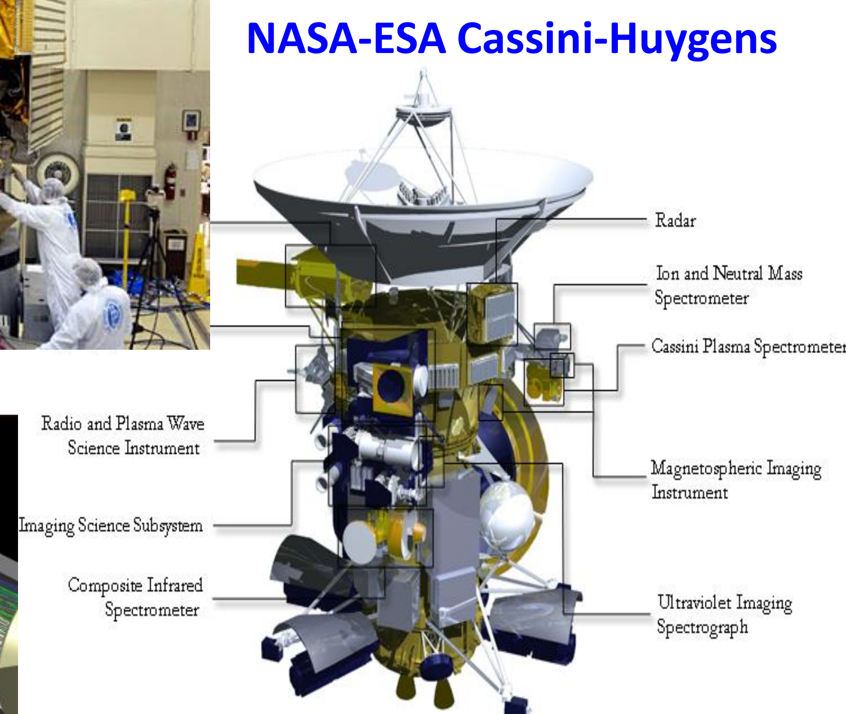
• Large variations are encountered in
- Size, shape, and rotation rate
- Absolute temperatures
-Thermal variations
- Surface compositions and activity
- Atmospheric densities, cloud cover, gas compositions
- Solar intensities
- Radiation environment
- Planetary protection requirements
- Magnetic and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

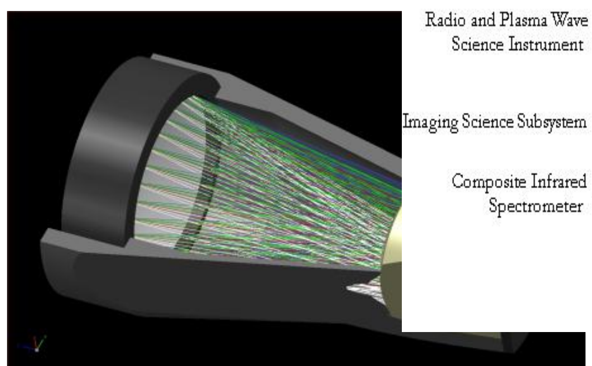
• Flight qualification to high TRL (“relevant environment”) is therefore target body-specific

Exploring our Solar System requires a Diversity of *Flight Ready Instruments*









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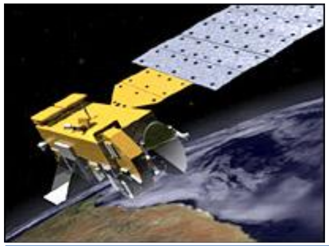
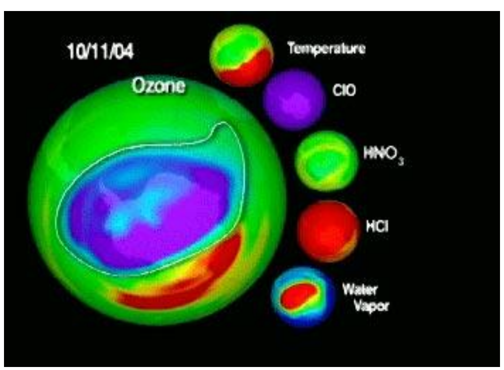
Typical Remote Sensing (Orbiter) Payloads



Earth Aura Satellite

Instruments
Scanning IR limb sounder (HIRDLS)
Microwave limb sounder/ radiometer (MLS)
UV spectrometer for ozone, aerosol (OMI)
Thermal emission FTIR imaging spectrometer (TES)



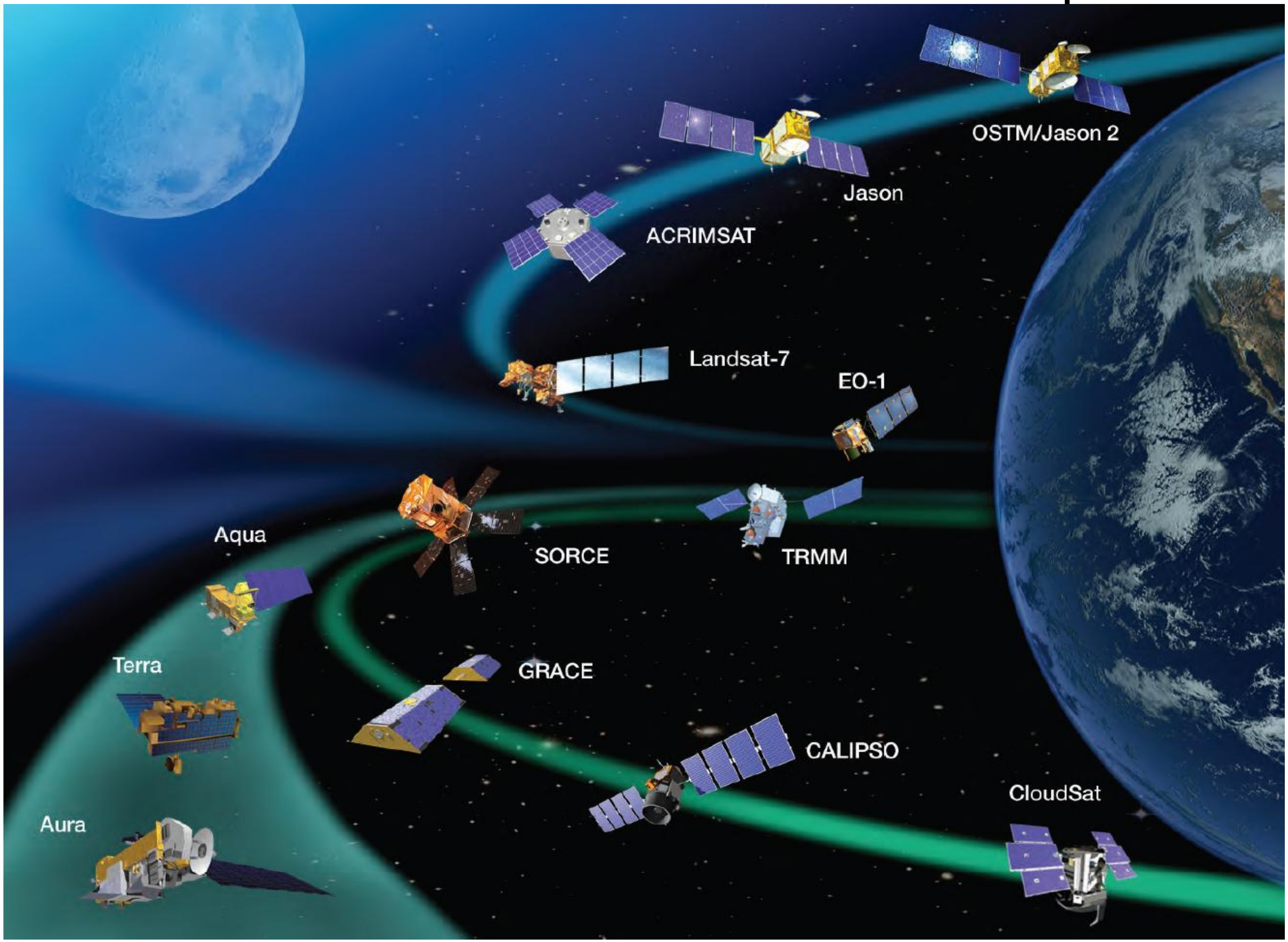
Mars Reconnaissance Orbiter (MRO)

Instruments
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

Instruments
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 Spect. (INMS)
Particle &Plasma Instr. (PPI)

Current NASA Earth Science Missions in Operation



Earth Science Missions

Foundation Missions

Glory—2010 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.
Aquarius—2011 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.
NPOESS Preparatory Project—2011 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.
Landsat Data Continuity Mission—2012/13 Strategic mission; Systematic measurement/mandated data continuity	Continues long-term global land cover change data record. Includes thermal infrared sensor. Joint mission with USGS.
Global Precipitation Measurement—2013 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.

Climate Continuity Missions

Orbiting Carbon Observatory-2 (OCO-2)—2013 Earth System Science Pathfinder
Stratospheric Aerosol and Gas Experiment - III (SAGE III)—Available 2014
Gravity Recovery and Climate Experiment Follow-on (GRACE FO)—2016
Pre-Aerosol, Clouds, and Ocean Ecosystem (PACE)—2018

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.

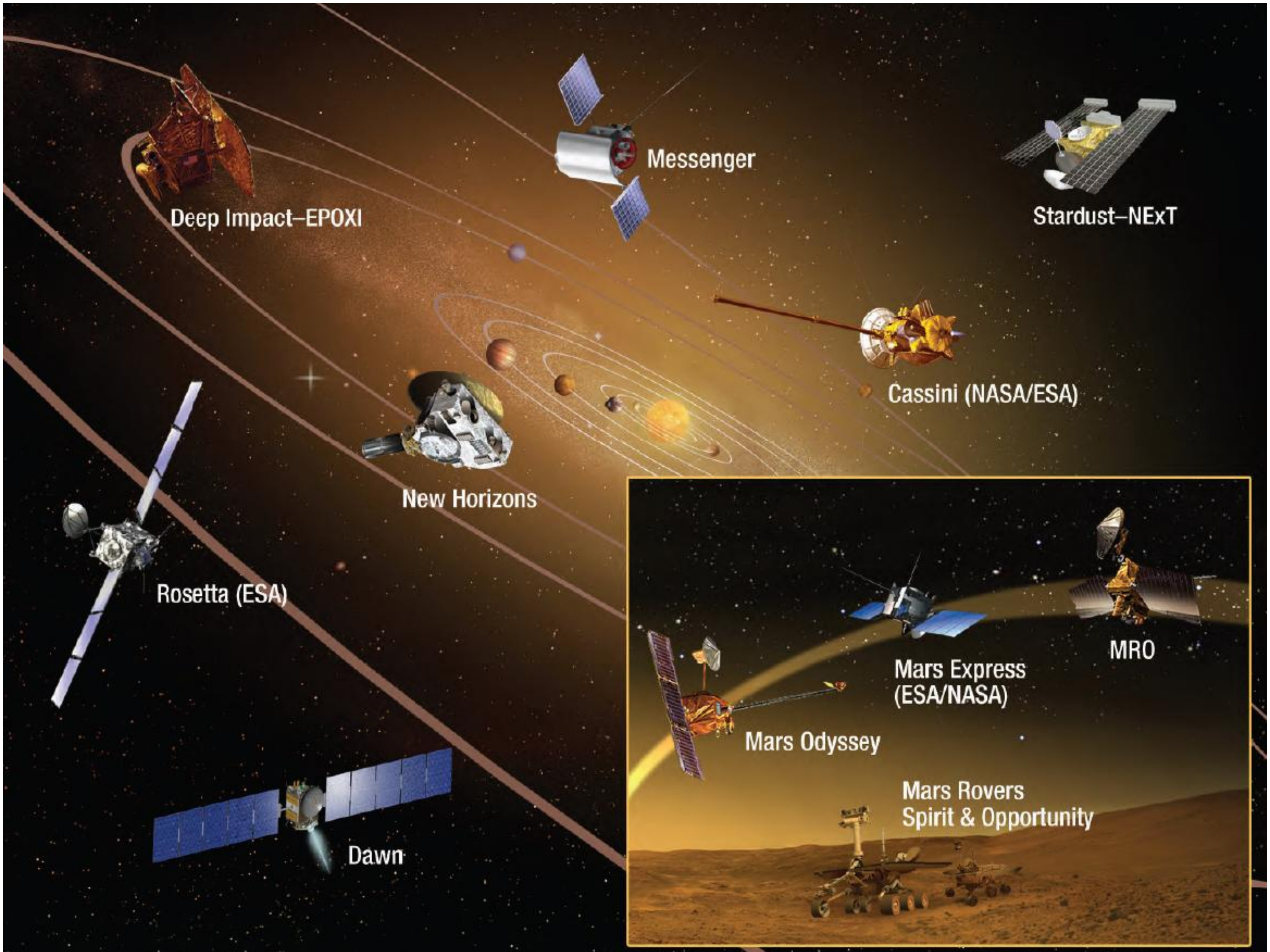
Tier 2 Missions

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

Current Planetary Science Missions in Operation



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Planetary Science Missions

Missions in Development

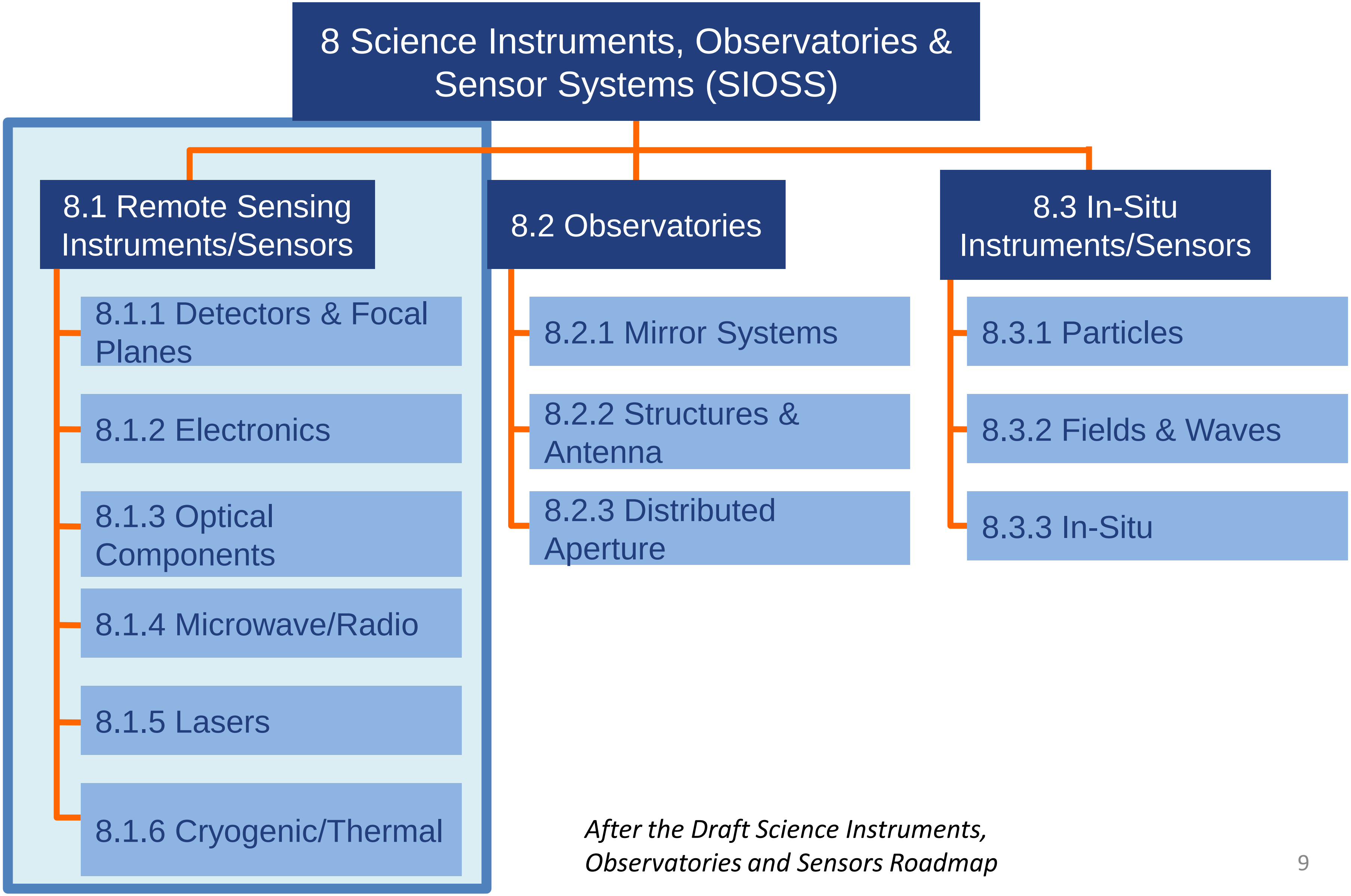
Mars Science Laboratory—2011 Strategic mission; Mars Exploration Program	Roving analytical laboratory to address questions of habitability. High-priority medium class mission in 2003 decadal survey; developed as a flagship-class mission.
Juno—2011 Competed mission; New Frontiers 2	Jovian gravity, composition, and magnetic fields. High-priority medium class mission in 2003 decadal survey; also high priority in Heliophysics decadal survey.
Gravity Recovery and Interior Laboratory (GRAIL)—2011 Competed 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.
Lunar Atmosphere and Dust Environment Explorer (LADEE)—2012 Strategic mission; Lunar Quest Program	Small mission to study the tenuous atmosphere of the Moon and the dust lofted into the atmosphere.
Mars Atmosphere and Volatile EvolutioN (MAVEN)—2013 Competed 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.

Future Missions

ExoMars Trace Gas Orbiter—2016 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.
Discovery-12—2015/17 Competed mission	Opportunity for a medium planetary mission; solicitation in 2010.
New Frontiers 3—2018 Competed mission	Three candidates selected for concept studies; asteroid sample return, lunar south pole/Aiken Basin sample return, and Venus atmosphere and surface probe. SMD will select one in 2011 for development.
Mars 2018—2018 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.
Europa Jupiter System Mission—early 2020s 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.
Mars Sample Return—mid 2020s Strategic mission	Flagship mission to return the samples collected by the Mars 2018 mission. Joint NASA-ESA campaign of three shared mission elements and their respective launches.

From the Planetary Decadal Survey

Technology Area TA8 Roadmap for Science Instruments, Observatories, and Sensor Systems- Structure Breakdown



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

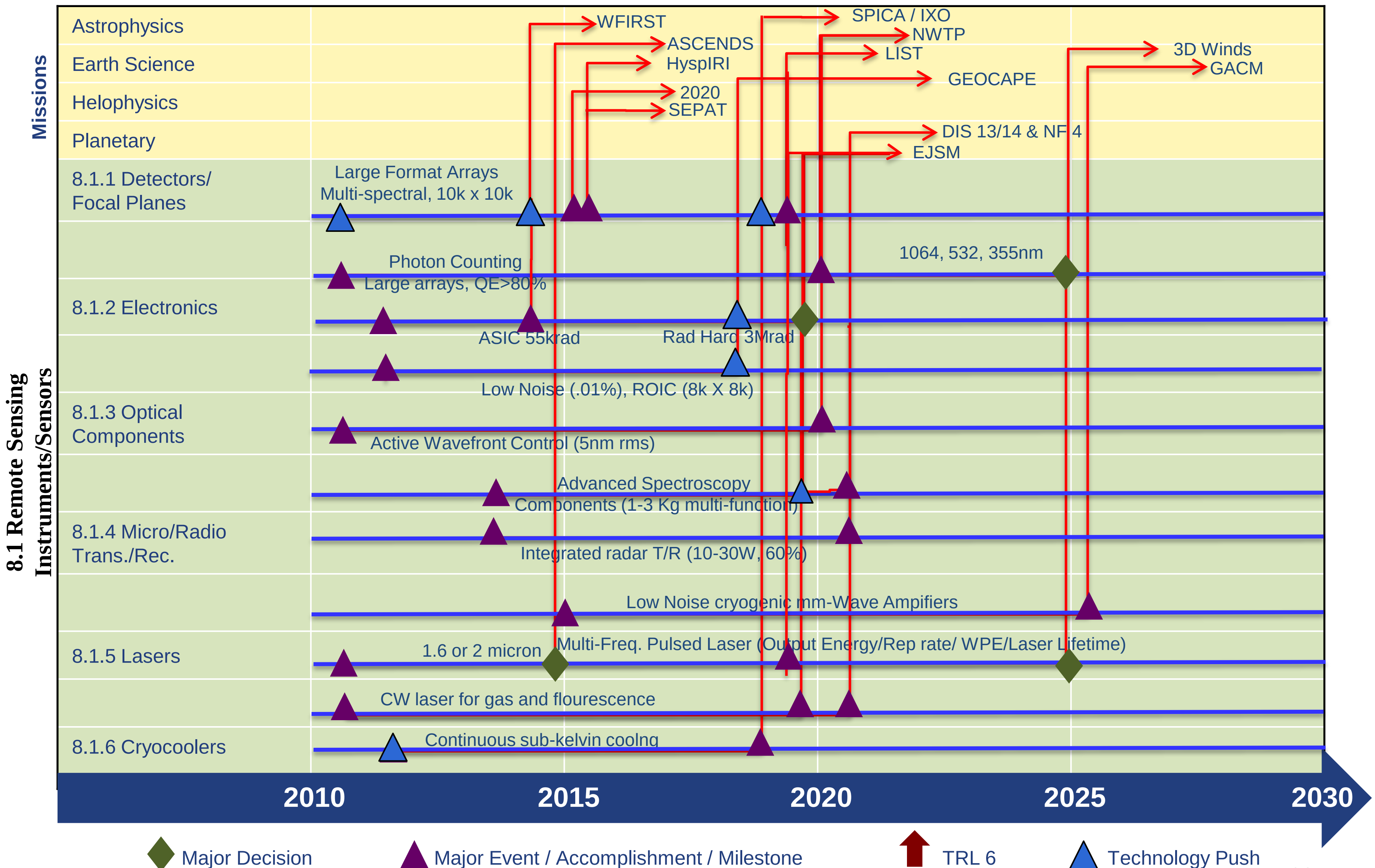
8.1.5.1 Pulsed Lasers
8.1.5.2 CW Lasers

(8.1.6) Cryogenic/Thermal

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

From the Draft Science Instruments, Observatories and Sensors Roadmap

8.1 Remote Sensing Instruments/Sensors



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/lambda>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: 5µcy/√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

From the Draft Science Instruments, Observatories and Sensors Roadmap

Top Technology Challenges Mid- and Long- Term

2017 to 2022 (Mid Term)

- **High-Contrast Exoplanet Technologies**
  - High-contrast nulling and coronagraphy ($1x10^{-10,}$ broadband); occulters (30 to 100 meters, < 0.1 mm rms).
- **Ultra-Stable Large Aperture UV/O Telescopes**
  - > 50 m^2 aperture, < 10 nm rms surface, < 1 mas pointing, < 15 nm rms stability, < $2M/$m^2$
    - 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

(8.1.1) Detectors and Focal Planes

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(8.1.2) Electronics

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

(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
NEED? Innovative architectures
NEED? Low mass (large) antennas

(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
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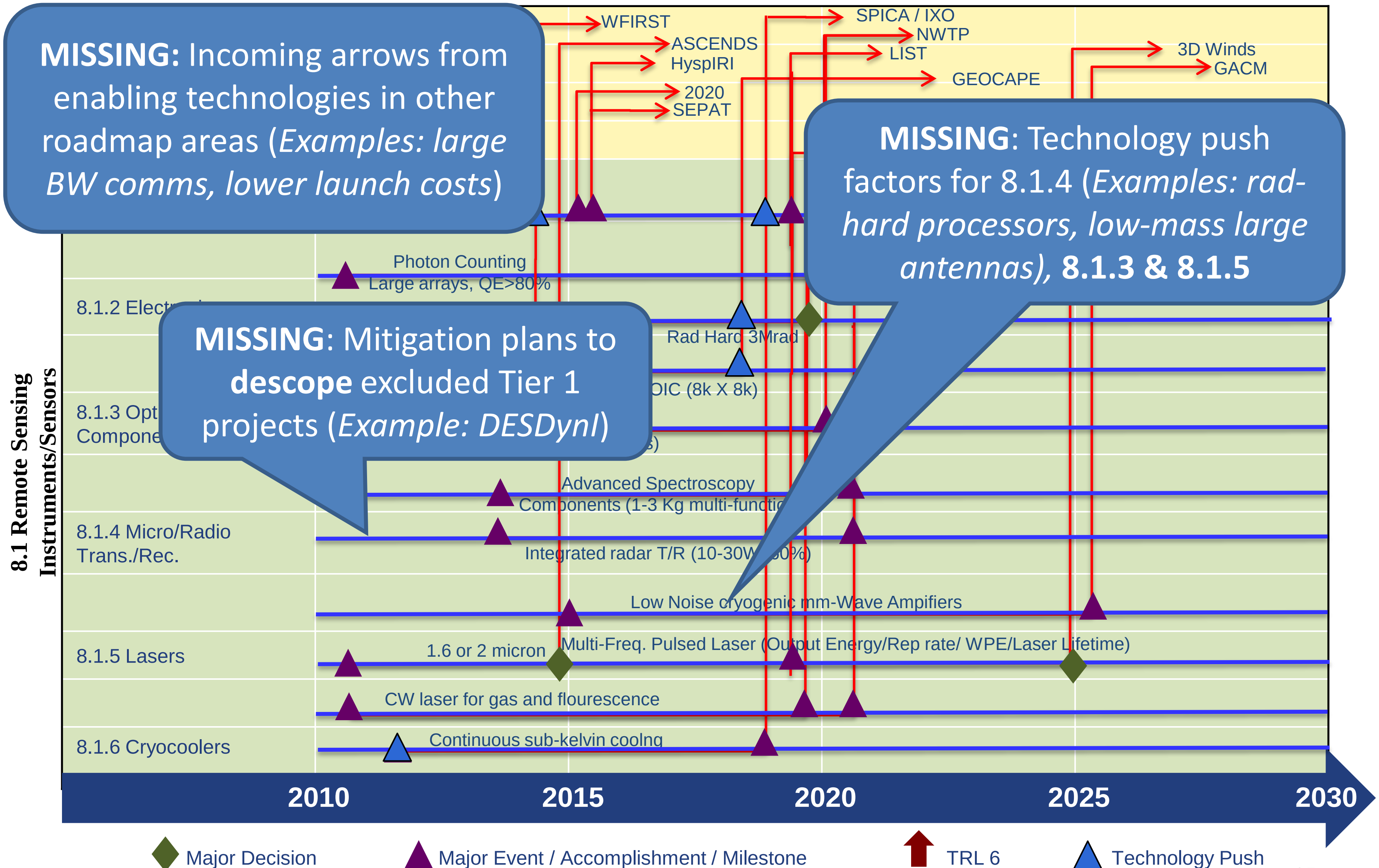
Missing dimensions: Examples



After the Draft Science Instruments, Observatories and Sensors Roadmap

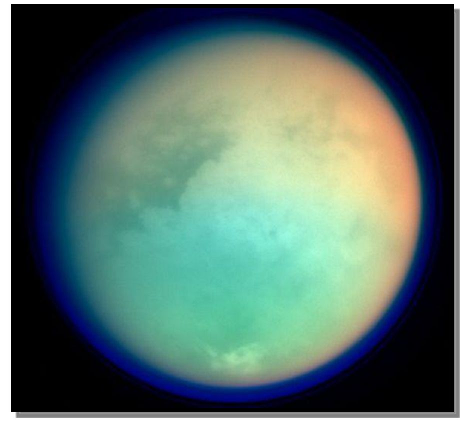
Planetary Decadal Survey 2011 Highlights

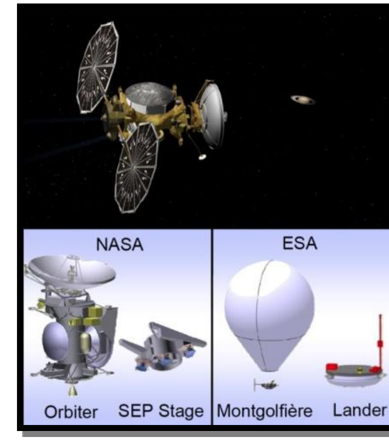
- **Continue ongoing missions;**
  - Discovery (MESSENGER , Dawn, Kepler, GRAIL
  - New Frontiers: (New Horizons, Juno, NF-3 TBD)
  - Others (Cassini, ODY/MRO/MER, MSL, MAVEN , LADEE, Mars 2016)
- **R&A: Increase the R&A budget over inflation;**
- **Discovery Program**
  - Continue with a regular <24-month 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

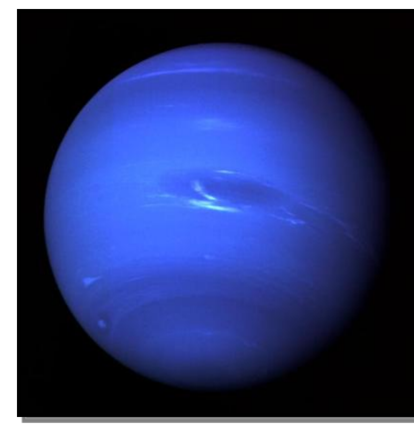
Planetary Decadal Survey 2011 Highlights

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







Slide modified from Steve Squyres presentation- March 2011

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 11.2 An Example of a Possible Technology Investment Profile That Would Be Appropriately Balanced for the Future Requirements for Solar System Exploration

Technology Element	Percentage Allocation	Key Capabilities
Science instruments	35	Environmental adaptation Radiation tolerance In situ sample analysis and age dating Planetary protection
Extreme environments	15	High temperature and pressure Radiation tolerance (subsystems) Cryogenic survival and mobility
In situ exploration	25	Sample acquisition and handling Descent and ascent propulsion systems Thermal protection for entry and descent Impactor and penetrator systems Precision landing Mobility on surfaces and in atmospheres Planetary protection
Solar system access and core technologies	25	Reduced spacecraft mass and power Improved interplanetary propulsion Low-power, high-rate communications Enhanced autonomy and computing Aerocapture Improved power sources Innovative mission and trajectory design

Slide modified from Steve Squyres presentation- March 2011

Planetary Decadal Survey- Summary of Potential Technology Requirements for Missions 2023-2033

Table 11.1

Objective: 2023-2032	Mission Architecture	Key Capabilities
Inner Planets		
Venus climate history	• Atmospheric platform • Sample return	• High-temperature survival • Atmospheric mobility • Advanced chemical propulsion • Sample handling
Venus/Mercury interior	Seismic networks	• Advanced chemical propulsion • Long duration high-temperature subsystems
Lunar volatile inventory	Dark crater rover	• Autonomy and mobility • Cryogenic sampling and instruments
Mars		
Habitability, geochemistry, and geologic evolution	Sample return	• Ascent propulsion • Autonomy, precision landing • In situ instruments • Planetary protection
Giant Planets and their Satellites		
Titan chemistry and evolution	Coordinated platforms: orbiter, surface and/or lake landers, balloon	• Atmospheric mobility • Remote sensing instruments • In situ instruments-cryogenic • Aerocapture
Uranus and Neptune/Triton	Orbiter, Probe	• Aerocapture • Advanced power/propulsion • High-performance telecom • Thermal protection/entry
Primitive Bodies		
Trojan and KBO composition	Rendezvous	Advanced power/propulsion
Comet/asteroid origin and evolution	• Sample return • Cryogenic sample return	• Advanced thermal protection • Sampling systems • Verification of sample—ices, organics • Cryogenic sample preservation • Thermal Control during entry, descent, and landing

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