Technology Development for Planetary Science Missions

James Green
NASA, Planetary Science Division
July 13, 2017

NAS Planetary Decadal Mid-Term

Outline

- PSD Response to Technology Development in the Planetary Decadal
- Specific Topics to be Addressed as Requested:
  - Electric Power
  - Electric Propulsion forecasted ISP Improvement timeline versus mission needs
  - Planetary Relay Optical Comm Concepts and Implementation timeline
- Detector/Instrumentation Development
- Planetary Data System

Visions and Voyages

"The committee unequivocally recommends that a substantial program of planetary exploration technology development should be reconstituted and carefully protected against all incursions that would deplete its resources. This program should be consistently funded at approximately 6 to 8 percent of the total NASA Planetary Science Division budget."

"The committee recommends that the Planetary Science Division's technology program should accept the responsibility, and assign the required funds, to continue the development of **the most important technology items** through TRL 6."

Technology Investment Categories

- Spacecraft: Broad and Mission-Specific

- Instruments: Broad and Mission-Specific

- Mission Support:
  - Tools(technology analysis, mission analysis, technology development)
  - Facilities (necessary for technology development)
  - Processes (necessary for technology utilization)

- Management:
  - Studies
  - Planning, Documentation and Communication

PSD Technology Funding by Category

FY16 Total = $243M (All)

(Technologies only = $96.3M)

RPS
$28.6M
($15.3M)

TTDP ($9.6M)
SCTDP($5.7M)
Management ($2.5M)
M2020 ($1.3M)
MMLAE ($2.2M)
PP&A ($5.3M)
Reserves ($1.5M)
EPO ($0.5M)

DOE
$72.8M
($0)

Plutonium ($17.0M)
Capability ($55.8M)

AMMOS
$34,9 M
($1.0M)

Technology ($1.0M)
Maintenance ($5.6M)
Operations ($2.5M)
Implementation ($6.9M)
Management/
Engineering ($18.9M)
Carry forward (-$1.7M)

Adv.Tech
$32.5M
($7M)

LILT solar ($0.6M?)
HotTech ($5M)
ColdTech ($1.4M)
Dyn pow conv ($13M?)
Tech Plan ($6M)

Icy Satellites Tech
$25.0M
($25.0M)

ColdTech $23.5M of which
~ $10M Instruments

Instruments ($1.5M)

R&A Instruments
$19.3M
($19.3M)

PIDDP
($0.3M)

MatISSE
($3.3M)

Picasso
($8.7M)

Pstar
($6.5M)

MMAMA ($0.2M)
ASTID)$0.3M)

MEP Tech
$4.0M
($3.7M)

MAV ($1.6M)
Containment Assur. ($1.8M)
Sample Integrity testing ($0.1M)
Studies and Research ($0.2M)
Other NASA costs ($0.1M)
Management ($0.2M)
Carry in/out ($0.24/0.3M)

NEOO Tech
$1M
($1M)

Array Radar ($1M)

Europa Tech Mat
$7.4M
($7.4M)

Surf. Sampling Sys ($3.2M)
Power Storage (0.5M)
Intell. landing Sys. ($3.6M)
PP Study ($0.1M)

Discovery Tech
$9.4 M
($9.4M)

Strat Balloon Tech ($4.9M)
NEXT ($2.6M)
HiVHAc ($0.3M)
DSOC - ($0.6M)
Phase A studies/TBD ($1M)

NF Tech
$7.2M
($7.2M)

Sample Tech for CSSR ($916k) APIC ($1.2M)
Nav Doppler Lidar Sensor ($817k)
Atm Const Exp Syst for Plan. Probes ($1.0M)
TLS for SP & VISE NF Missions ($881k)
POGO for Aster. Expl ($833k)
MEMS Micro-Conc. for LILT Missions ($1.0M)
Venus Entry Probe Prototype ($539k)

PSPS
$0.9M

Planning/
Support ($0.9M)

Blue text – Total funds in category
Black text – Actual Technology funded
Green text - Co-funded with STMD
Maroon Text – Management/other

🟨 = Technology Funding Line
🟦 = Mission Funding Lines
🟪 = Research & Analysis Funding Line
🟥 = Instrument Development
🟫 = Technology Planning and Support

Technologies to Support Missions

- Technology investments to support future missions:
  - NEXT, DSOC, HEET to support Discovery & New Frontiers AO
  - Homesteader to prepare instruments for New Frontiers AO
  - ICEE to prepare for Europa Clipper Instrument AO
  - COLDTECH to prepare for Europa Lander Instrument AO
  - HOTTech in Advanced Technology for a potential future Venus or Mercury mission
  - PICASSO and MatISSE are the general instrument calls

SPACE TECHNOLOGY MISSION DIRECTORATE

PSD Co-Funded Technologies

Spacecraft Technology

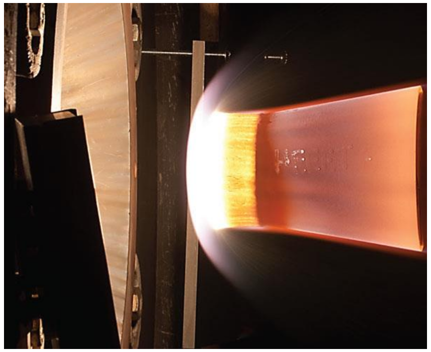
- Heat Shield for Extreme Entry Environment Technology
- Extreme Environment Solar Power
- Deep Space Engine
- Bulk Metallic Glass Gears

Core Technology

- High Performance Spaceflight Computing
- Entry System Modeling

Instruments

- Mars Science Laboratory EDL Instrument II



Heat shield material testing (HEEET)
Potential mass savings for missions to Venus, Mars, and the outer planets

Bulk metallic glass gear testing.
Amorphous metal doesn't get brittle in the cold, requires no lubricant.

Deep Space Engine
Lower mass, smaller volume,
lower cost for landers and orbiters

PSD Technology Roadmapping

- Surveyed the VEXAG, OPAG, SBAG, Mars Program, and the Decadal Survey
- Technologies to enable: innovative science, in more extreme environments, on smaller missions, on a more frequent cadence
    - Expect our top technologies to include: Radioisotope Power, Electric Propulsion, Communications, Detectors/Instruments, “Cold” Technology, “Hot” Technology, SmallSat Technology
- Worked with NASA Centers to assess each technology identified by the AGs using the following Figures of Merit
    - Critical Technology for Future Mission(s) of Interest
    - Degree of Applicability across PSD Missions/needs
    - Work Required to Complete
    - Opportunity for Cost Sharing
    - Likelihood of Successful Development and Infusion
    - Commercial Sustainability

Technology Roadmap

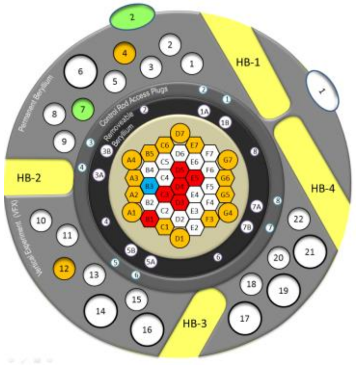
Context → Goals → Costs/Schedules → Priorities

- Placing Each Technology In Context (with NASA GRC, GSFC, MSFC, ARC, JPL)
  - Mapping the technologies to capabilities, functionalities, destinations, and time frames.
- For Each PSD Prioritized Technology, Identify:
  - The state-of-the-art
  - A quantitative technology goal
  - A description of what science that buys if successful
- Determine, To Reach The Goal:
  - How much will it cost
  - How long it will take
  - How will we get it done
- HQ PS/PE review of Context (Mission Application)
- Technology PPBE review
- Technology coordination function under consideration
  - Coordinates technology investment strategy
  - Tracks technology investments across PSD and NASA

Planetary Science Division Prioritization

	Prioritized Technologies
Ocean Worlds	Low temp compatible, low power, rad-hard electronics
	Low temp compatible actuators/mechanisms
	Planetary Protection Techniques/component and material compatibilty
	Sub-surface (>0.2 m) ice acq and handling
	ice sample return
	pinpoint landing on Titan
Planetary Missions	High performance/low power/rad hard computing and FPGAs
	Low intenstiy/low temp solar power
	RPS surface power
	RPS orbital power
	System autonomy (GNC, Prox Ops, C&DH, sampling ops, FDIR)
	Power, GNC, Propulsion, comm for small s/c
	high bandwidth and datarate comm
	high temp-compatible electronics
	high temp-compatible power systems
	planetary ascent vehicle for sample return
	heat shield technologies for planetary entry and sample return
Europa	surface cryogenic ice sample acq and handling
	low temp batteries
	pinpoint landing on Europa
	landing hazard avoidance
Inst.	life detection for ocean worlds
	low mass, low power instruments for cold, high rad ocean world environmnents
	low mass, low power instruments for small spacecraft

Radioisotope Power



Reflector positions can be used to irradiate NpO_2 in the HFIR

Radioisotope Power

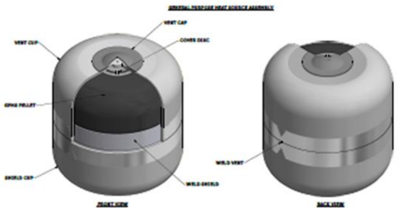
Aqueous Processing Line at Los Alamos

<u>Constant Rate Production of PU238</u>

Provides flexibility to allow for surge capabilities

Alleviates process and production limitations

- Leverages DOE standard campaign model providing flexibility for NASA missions
- Reduces mission risk by maintaining qualified work force and making targeted equipment investments across the supply chain
- Reduces mission costs by approximately 25%
- By fiscal year 2019
  - Maintain average production rate of 400 g/y
- By fiscal year 2021
  - Add additional irradiation capability at the Advanced Test Reactor (ATR) for redundancy
  - Maintain 10-15/year constant-rate of fueled clads
- By fiscal year 2025
  - Maintain average production rate of 1.5 kg/y with surge capacity to ~2.5 kg/y
  - Completed modernization campaign at Los Alamos to improve reliability of critical infrastructure and enhance worker safety



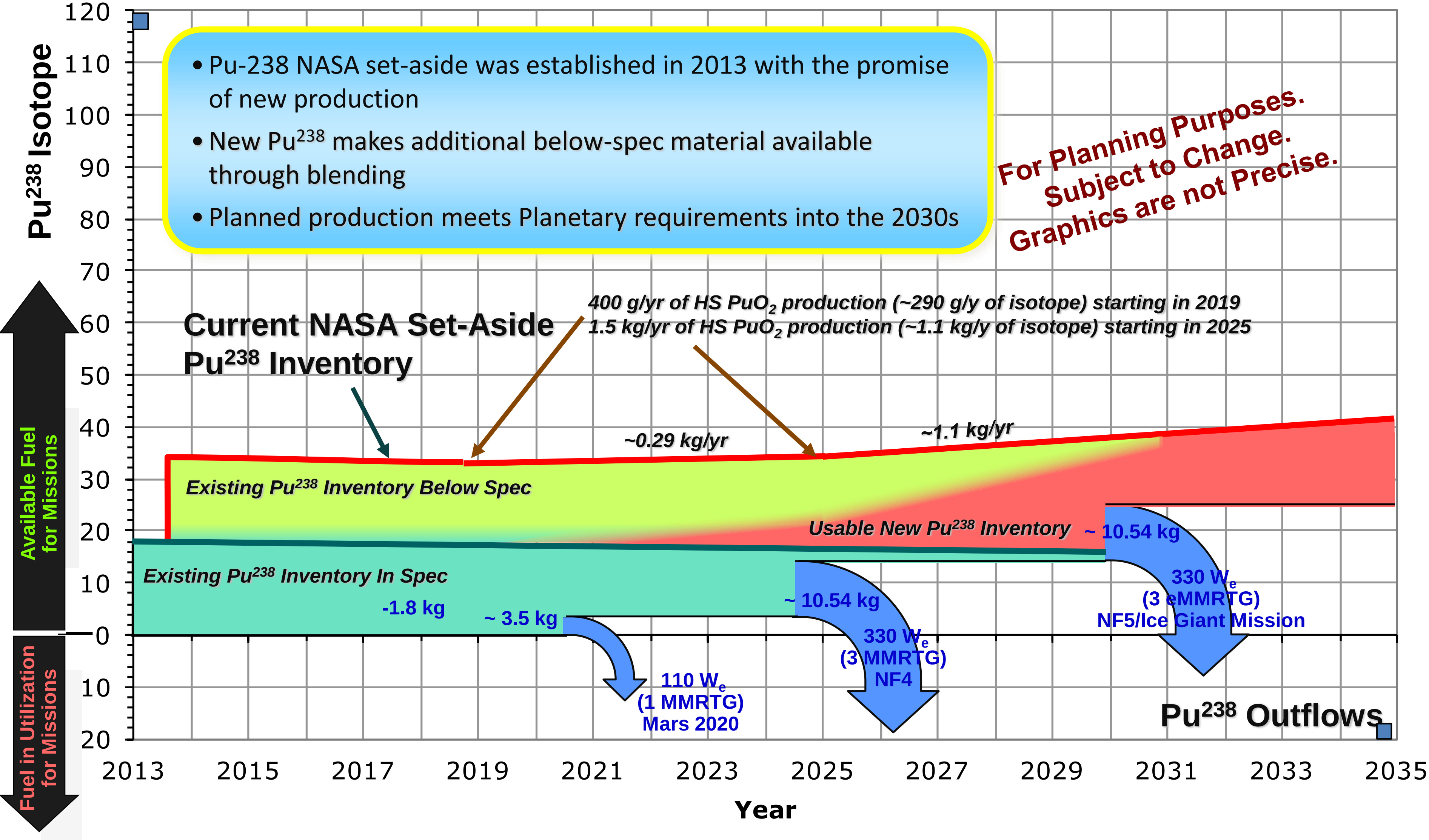
Fueled Clad
4 needed for a GPHS

Radioisotope Power

NASA Set-Aside Plutonium vs Planetary Requirements

Current Projections with Baseline Production Rates

- Pu-238 NASA set-aside was established in 2013 with the promise of new production
- New Pu^{238} makes additional below-spec material available through blending
- Planned production meets Planetary requirements into the 2030s



For Planning Purposes.
Subject to Change.
Graphics are not Precise.

June 2017

Radioisotope Power

SMD RPS Mission Planning Set

	Projected Launch Year	Power Reqmnt (W_e)	RPS Type	Plutonium Heat Source (Fueled Clads)
Mars 2020 (in development)	2020	110	1 MMRTG	32
New Frontiers 4 (proposed)	2025	110-330	1-3 MMRTGs	32-96
New Frontiers 5 (projected)	2029-2030	110-300	1-3 eMMRTGs or Next Gen	32-96
Ice Giants (under study)	2031-2033	550	1 Next Gen	64

DOE has enough heat source material in hand to fuel 4 MMRTGs

- Enough to support NASA needs while DOE shifts to the constant rate production model

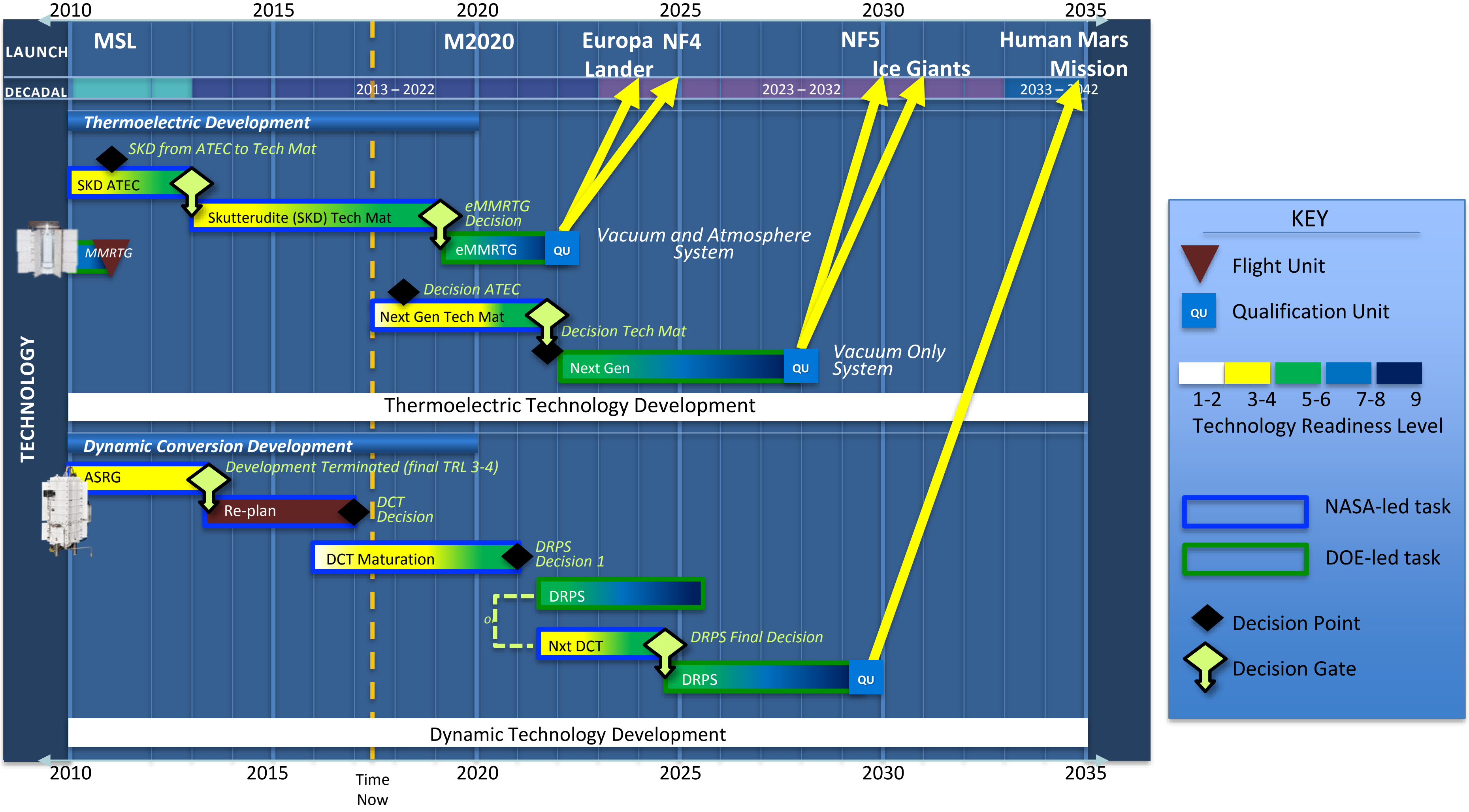
	Year	PU-238 Production Rate	Plutonium Heat Source (Fueled Clads)
Near Term	FY19	400 g/year (avg)	
Mid Term	FY21		10-15/year constant-rate
Far Term	FY25	1,500 g/year (avg) 2,500 g/year (surge)	

NASA expects 2 to 3 nuclear missions per decade

Radioisotope heater units may be required on these and other missions

Radioisotope Power

RPS Technology Notional Roadmap



Electric Propulsion

Electric Propulsion

NASA's Evolutionary Xenon Thruster – Commercialization (NEXT-C)

Goal

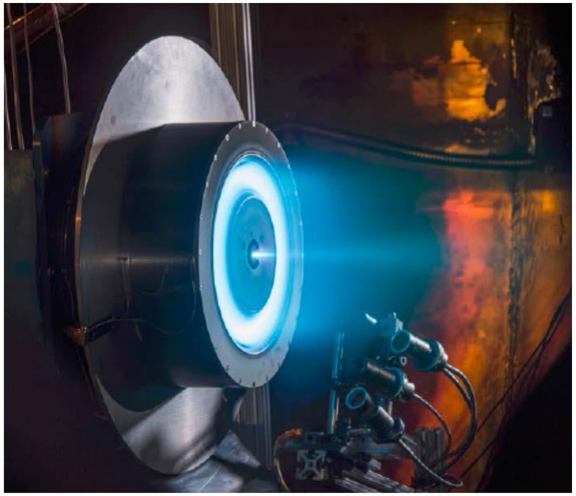
- Mature the thruster and power processing unit (PPU) elements from TRL 5/6 to TRL 8
- Provide two flight fidelity thrusters and PPUs for New Frontiers Announcement of Opportunity or other future NASA science mission
- Establish a commercial platform for high-power ion thruster engines

Status

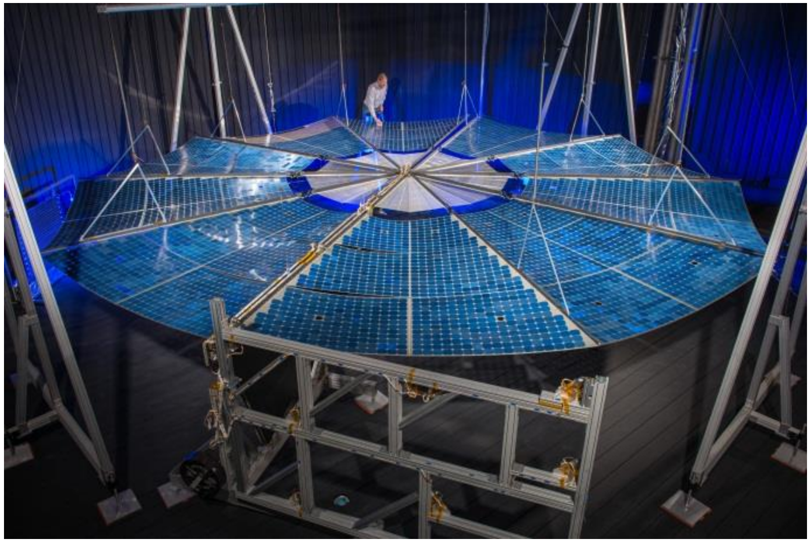
- Development thruster testing is currently ongoing at GRC in VF-16.
- Full thermal vacuum testing of the prototype PPU will occur over the summer.
- Integrated system CDR is planned for December 2017.
- Flight hardware build of two PPUs and two thrusters will begin in 2018.

SPACE TECHNOLOGY MISSION DIRECTORATE

Solar Electric Propulsion Technology



- 12.5 kW Hall Effect Thrusters under development at Aerojet Rocketdyne
- 20 kW-class flexible blanket solar arrays ready for mission infusion
- Potential Future Planetary mission Application



ROSA demo on ISS June 2017

12.5 kW NASA HERMeS Thruster system (top)
20-kW class flexible blanket solar arrays: Orbital ATK MegaFlex (left), DSS Mega-ROSA (right)

Optical Communication

Communications Architecture

Deep Space Optical Communications

2018 – 2019	Ground validation
2022	Launch aboard Psyche
2022 – 2023	Data transmission up to 2.7 AU (longer and farther if possible)
2026	Arrival at (16)Psyche in the main asteroid belt

New SmallSat study has been commissioned

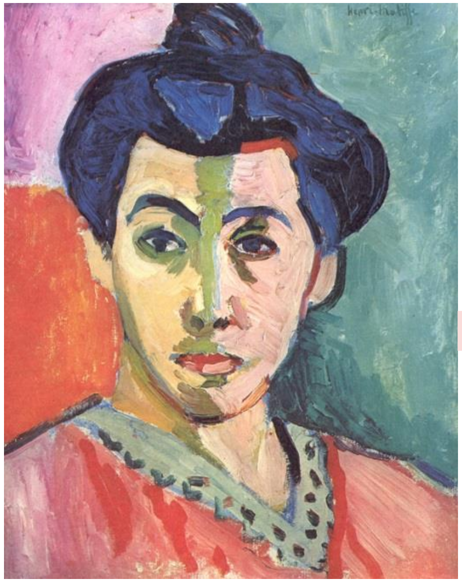
- Define a communications architecture for in-flight and flight-to-ground for planetary missions
    - Enable SmallSats as standalone or dependent missions
    - Leverage communication relay at Mars
- Define a standard for primary-to-SmallSat spacecraft communications

Instrument Development

Detectors/Instruments

From the Decadal Survey: “**The committee recommends that a broad-based, sustained program of science instrument technology development be undertaken**, and that this development 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.

PICASSO
TRL 1 – 4



MatISSE
TRL 4 – 6

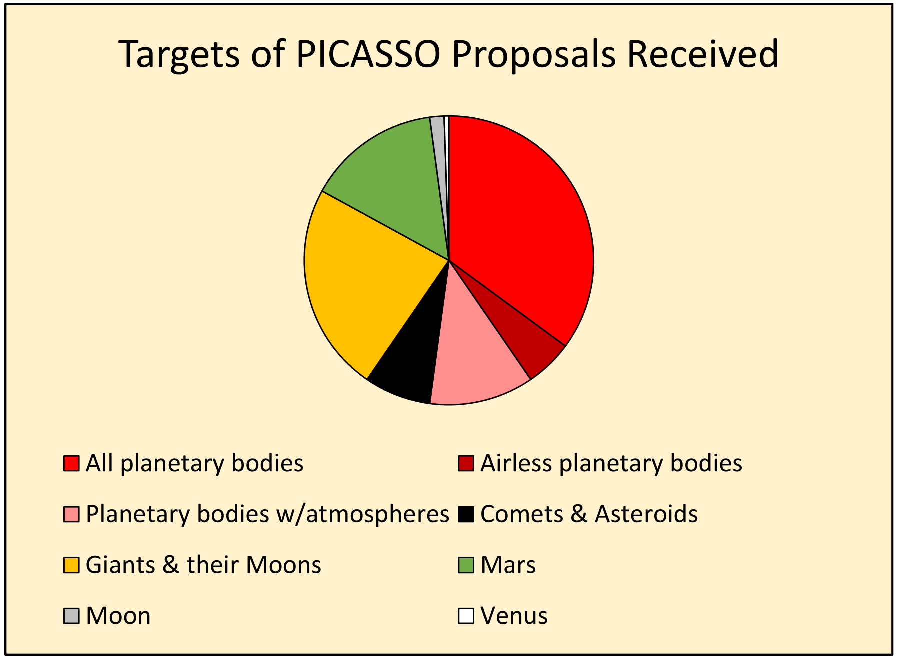
Flight Instrument
TRL 6 – 9

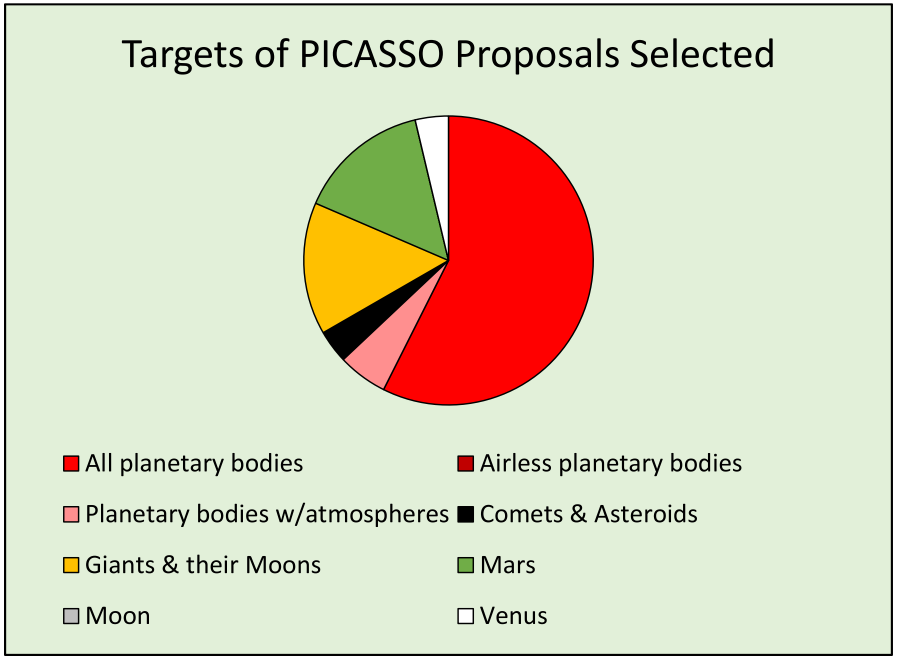
NEW Program funds the “valley of death”

Detectors/Instruments

PICASSO: Developing new instruments and detectors (Low TRL)

- 54 funded 2-3 yr activities over four years (~$850k/award)
  - PICASSO13: 12 funded from 114 proposals
  - PICASSO14: 14 funded from 96 proposals
  - PICASSO15: 12 funded from 113 proposals
  - PICASSO16: 17 funded from 85 proposals
- Wide variety of instruments, detectors, and targets


Targets of PICASSO Proposals Received

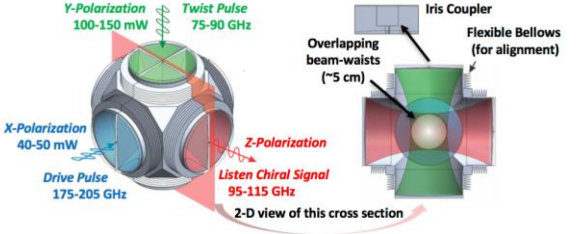

Targets of PICASSO Proposals Selected

Detectors/Instruments

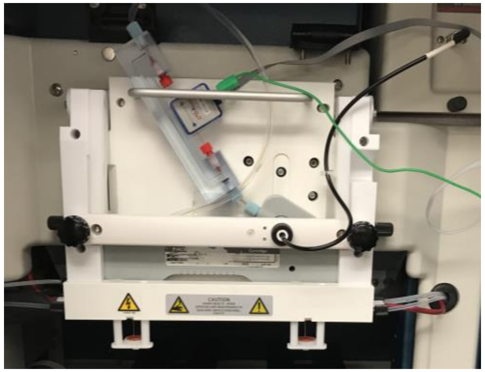
PICASSO: Developing new instruments and detectors for **life detection**

- **18** of 54 funded tasks directly relevant to Life Detection
- Wide portfolio

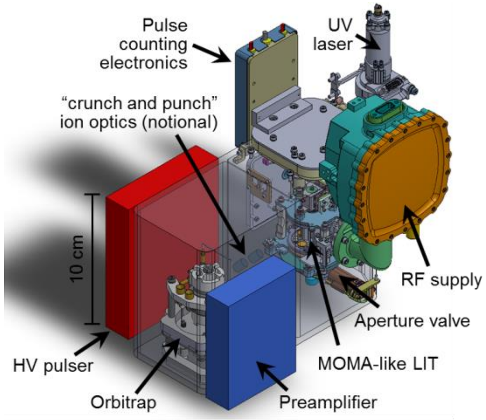
  Chromatography, Extraction, IR Micro imaging, Mass Spec, Microfluidics, mm wave, penetrator hardened instruments, Raman, Environmental SEM, Vis-UV imagers
- Low TRL
  - 2 target TRL 5
  - 10 target TRL 4
  - 3 target TRL 3
  - 2 target TRL 2



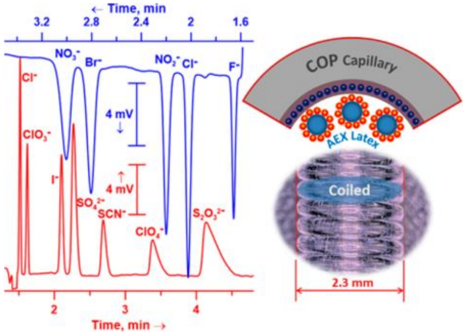
S. Yu (JPL) Chiral mm Spectroscopy



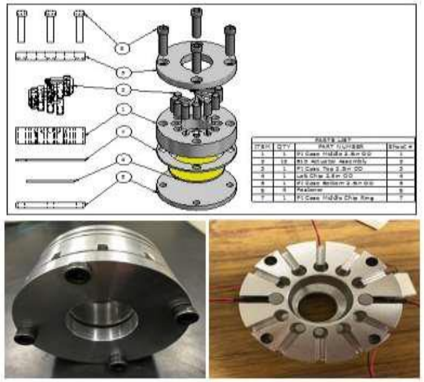
F. Mora (JPL) Microfluidic Ion Analyzer



R. Arevalo (GSFC) LIT/Orbitrap Mass Spec



P. Dasgupta (UT Arlington) Open Tube Chromotography

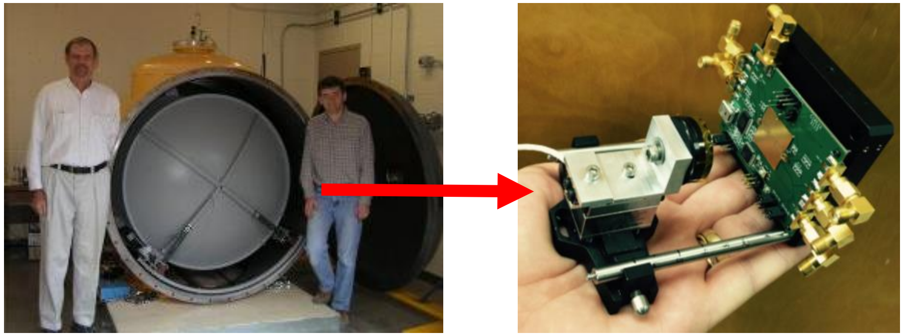


A. Stockton (GA Tech) Penetrator Hardened Organic Analyzer

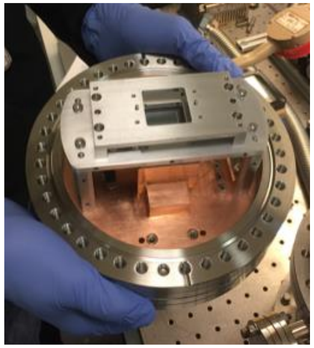
Detectors/Instruments

PICASSO: Developing new instruments and detectors for **Small Spacecraft**

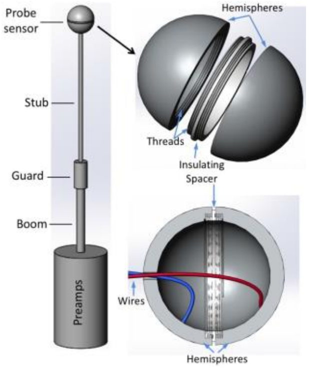
- **27** of 54 funded tasks directly relevant to Small Spacecraft
    - Less than 3U, 10 kg, and 10 W
- Wide portfolio
    - Atmospheres, Chromatography, Dust, Gamma Ray/neutron, Gravity, Heat Flow, Magnetometers, Plasma, Raman, Sampling, Seismometers, THz Spec, UV-Vis Imagers, XRF…
- Low TRL
    - 4 target TRL 5
    - 18 target TRL 4
    - 3 target TRL 3
    - 2 target TRL 2



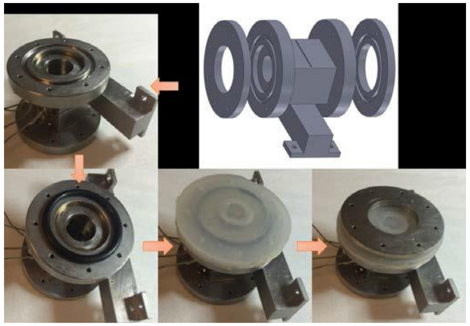
B. Drouin (JPL) – mm wave spectrometer



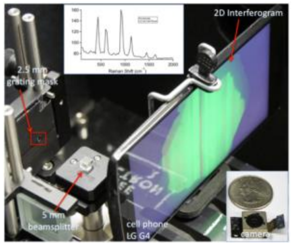
D. Blake (ARC) Map-X
X-ray µ-Mapping Spec



X. Wang (Colorado)
Plasma Probe



H. Yu (ASU) Micro Seismometer



S. Angel (U So Carolina)
Cell Phone Raman

Detectors/Instruments

MatISSE: maturing new instruments and detectors to TRL 6

21 funded tasks

Landers:

Spectrometers (imaging, Raman, mass, gamma ray),
Deep core drill technology,
Subsurface microwave/optical/electromagnetic sensor suite,
Fluorescence imager, Genome sensor

Orbiters:

Spectrometers (microwave, sub-mm, visible, UV),
Imagers (sub-mm, UV),
Subsurface radar, organics analyzer, atmospheric LIDAR

Flyby/Rendezvous:

Comet penetrator/sample extractor
Cosmic dust analyzer
Vector magnetometer

D. Lawrence (APL)
GeMini neutron spectrometer

Feature:

- GeMini neutron spectrometer recently selected for the Psyche mission High-heritage design based on MESSENGER GRNS and the Lunar Prospector Neutron Spectrometer (LP-NS)
- Work under MatISSE simplified the Ge sensor/cryostat, increased the cryocooler's reliability, and increased the data processing unit's capability.

“Cold” Technology
for Europa, Titan, Enceladus, Callisto, Ganymede, Ceres

COLDTech: Concepts for Ocean worlds Life Detection Technology

- Spacecraft-based instruments and technology for surface and subsurface exploration of ocean worlds
- Emphasis on the detection of evidence of life, sample acquisition, delivery and analysis systems, and technologies required to access oceans.
- 21 awards ($27 M investment over three years)

  In Situ Exploration and Core Technologies

  - Autonomous precision landing technology
  - Sample acquisition systems
    (ice penetration – melt, drills; plume sampling; sample delivery and processing)
  - Motor controller, rover wheels
  - NMR Detection of Extant Life

  Instruments and Sensors

  - Seismometers and sounders
  - Imagers (luminescence, visible)
  - Microfluidic wet chemistry laboratory
  - Supercritical CO_2 extraction and chiral supercritical fluid chromatography
  - Nanomotion sensor
  - Nanopore sequencing
  - Molecular sensor

“Hot” Technology for Venus, Mercury, Gas Giant Interiors

HOTTech: Hot Operating Temperature Technology

- Electrical and electronic systems for the robotic exploration of high-temperature environments (>= 500 °C).
- 8 awards ($4.5 M investment over three years)

Electronics

- High-temp electronic packaging for extreme environments
- Nano-triode vacuum devices for high temp environments
- High-temp oscillators and clocks for wireless communications

Sensors, Actuators, and Motors

- SiC electronics and sensors for high temp environments
- High-temp diamond-based electronic sensors and actuators
- High-temp electric motors and position sensors for Venus exploration

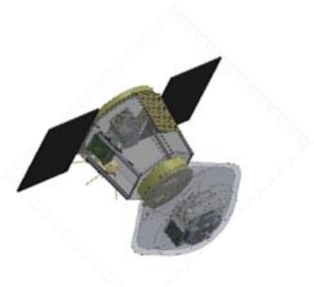
Power Generation

- Lithium-combustion based power generation in high-temp environments
- Low-intensity High-temp solar cells for extreme environments

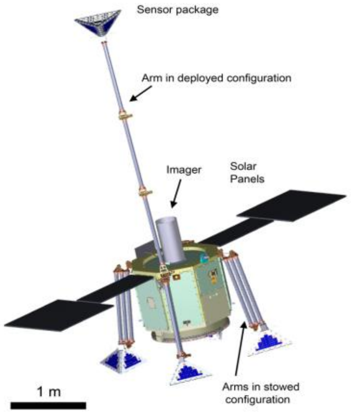
SmallSat Technology

PSDS3: Planetary Science Deep Space Small Satellite Studies

- 19 awards ($6 M investment over one year)
- Concept studies to scope science capability and cost of small secondary missions



Christophe Sotin (JPL)
Cupid's Arrow spacecraft concept



Jeff Plescia (Purdue)
APEX spacecraft concept

Venus

- Valeria Cottini, CUVE - Cubesat UV Experiment
- Attila Komjathy, Seismicity Investigation on Venus Using Airglow Measurements
- Tibor Kremic, Seismic and Atmospheric Exploration of Venus (SAEVe)
- Christophe Sotin, Cupid's Arrow

Moon

- David Draper, Innovative Strategies for Lunar Surface Exploration
- Charles Hibbitts, Lunar Water Assessment, Transportation, and Resource Mission
- Noah Petro, Mini Lunar Volatiles (MiLUV) Mission
- Suzanne Romaine, CubeSat X-ray Telescope (CubeX)
- Timothy Stubbs, Bi-sat Observations of the Lunar Atmosphere above Swirls (BOLAS)

Small Bodies

- Benton Clark, CAESAR: CubeSat Asteroid Encounters for Science and Reconnaissance
- Tilak Hewagama, Primitive Object Volatile Explorer (PrOVE)
- Jeffrey Plescia, APEX: Asteroid Probe Experiment

Mars

- Anthony Colaprete, Aeolus - to study the thermal and wind environment of Mars
- Michael Collier, PRISM: Phobos Regolith Ion Sample Mission
- Robert Lillis, Mars Ion and Sputtering Escape Network (MISEN)
- David Minton, Chariot to the Moons of Mars
- Luca Montabone, Mars Aerosol Tracker (MAT)

Icy Bodies and Outer Planets

- Kunio Sayanagi, SNAP: Small Next-generation Atmospheric Probe
- Robert Ebert, JUpiter MagnetosPheric boundary ExploreR (JUMPER)

SPACE TECHNOLOGY MISSION DIRECTORATE

Small Spacecraft Technology

Developing and demonstrating new capabilities for small spacecraft

Flight Demonstrations:

Coming soon

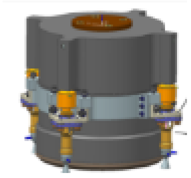
- Space-to-ground laser communications
- Laser ranging and tracking
- Ka-band communication
- Formation flight
- Proximity operations
- Radiation tolerant processors
- Autonomous rendezvous and docking

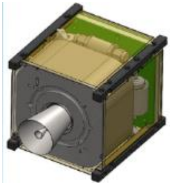
Recently completed

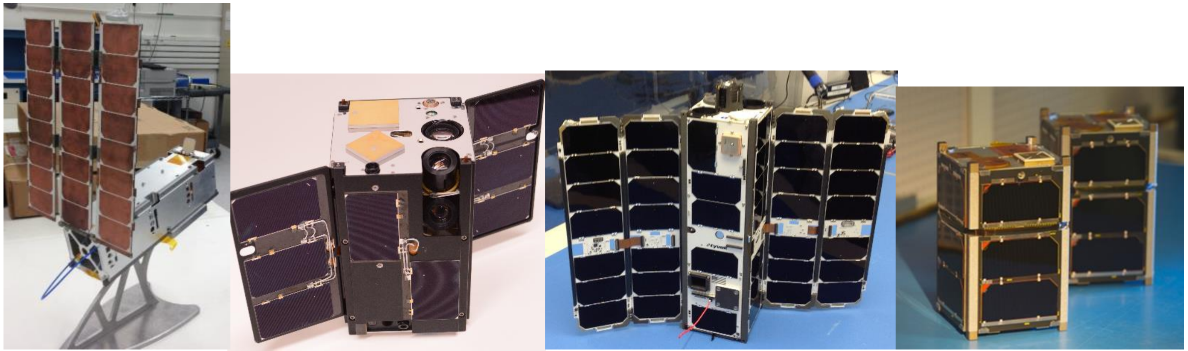
- Autonomous network communications
- Earth-return vehicle

Technology Development:

- Ka-band radio
- Low-cost atomic clock
- Star tracker
- Radar remote sensing
- Attitude control system
- Autonomous on-orbit assembly
- Inflatable deorbit device
- Cryo-cooler and active thermal control
- Solar arrays
- Propulsion systems
    - Chemical
        - Hydrazine; ‘green’
        - Hybrid $N_2$0/solid
        - Water electrolysis
    - Electric
        - RF-Ion (Xe and Iodine)
        - Hall effect (Iodine)
        - Electromagnetic; Electrospray
    - Solar sail control system

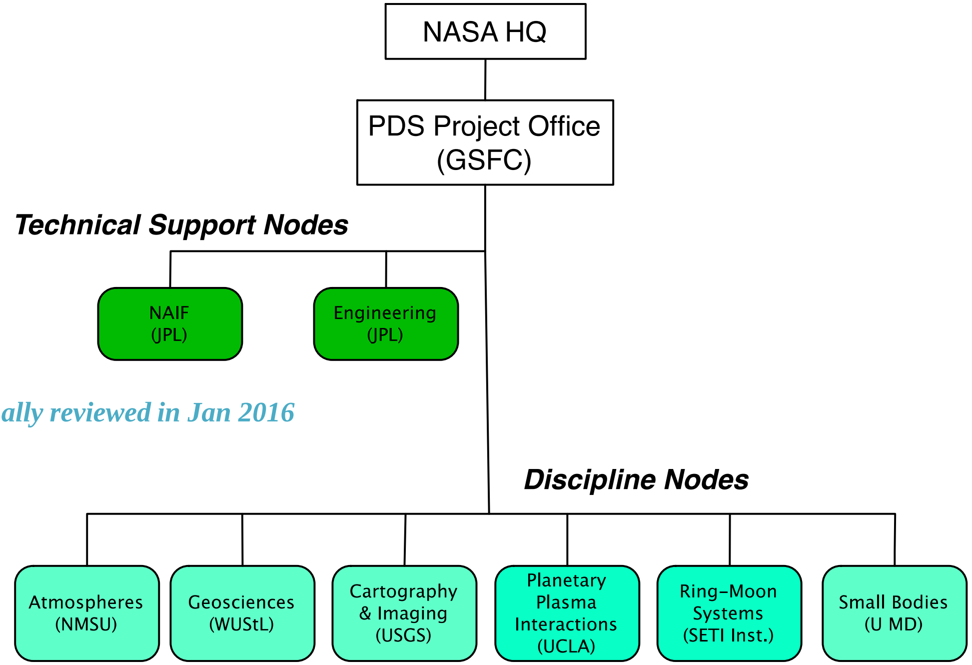






Planetary Data System

PDS Updates



Externally reviewed in Jan 2016

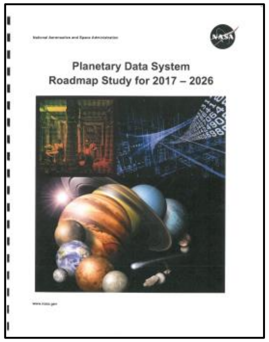
Chosen from open CAN in Aug 2015

Achievements Since Decadal Survey

- Openly competed all Discipline Nodes; first time in 10 years.
- Externally reviewed performance of the Technical Support Nodes.
- Developed and rolled out new data standard, PDS4.
  - First information model-driven data system in operational use.
- Expanded membership in the International Planetary Data Alliance.
  - IPDA adopted PDS4 as international standard.
- Renewed focus on development of user-focused tools.
- Began working with grantees to archive data products.
- Completed a new PSD roadmap

PSD Roadmap

- Produced over the course of a year by 14 members of the planetary science community (Ralph McNutt of JHU/APL, Chair)
- Roadmap Report summarizes:
  - Assessment of the current state of PDS
  - Highlights community-based findings regarding a variety of topics including tools, tutorials, archive efficiency,
  - The role of PDS in providing access to data generated by grants
- PSD Roadmap will serve as a guide for PDS operations that will evolve over the next decade



Planetary Data System
Roadmap Study for 2017 – 2026

https://pds.nasa.gov/roadmap/PlanetaryDataSystemRMS17-26_20jun17.pdf

Questions?