

National Aeronautics and Space Administration



Science Mission Directorate Strategic Technology

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Chief Technologist, Science Mission Directorate, NASA Headquarters

Presentation to Outer Planets Assessment Group (OPAG), August 2016

Heliophysics



Make possible accurate predictions of solar phenomena throughout the solar system

Earth Science



Enable accurate environmental predictions, including weather, climate, natural and human induced events

Planetary Science



Explore habitable environments across the solar system with human and robotic explorers

Astrophysics

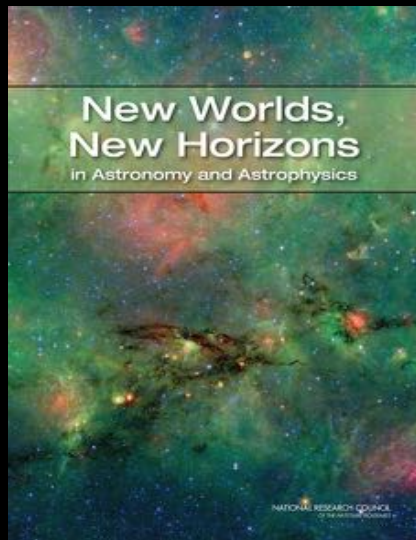


Are we alone? How did we get here?
How does the universe work?

Strategically Planned Science-Driven Missions

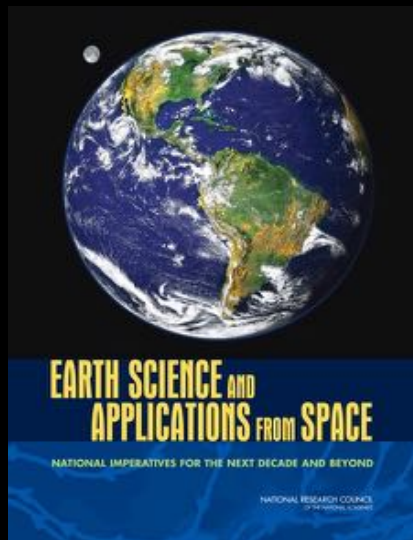
New Earth Science Decadal Survey now in planning stages

Astrophysics



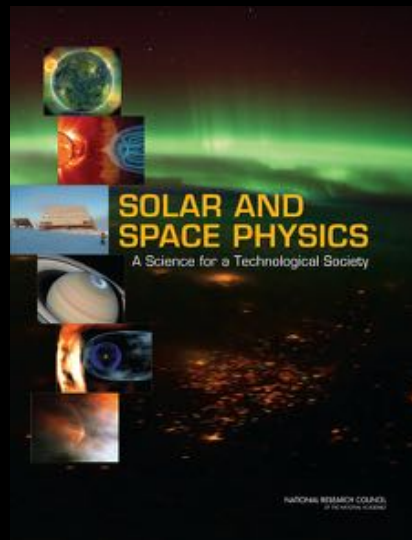
2012 – 2021

Earth Science



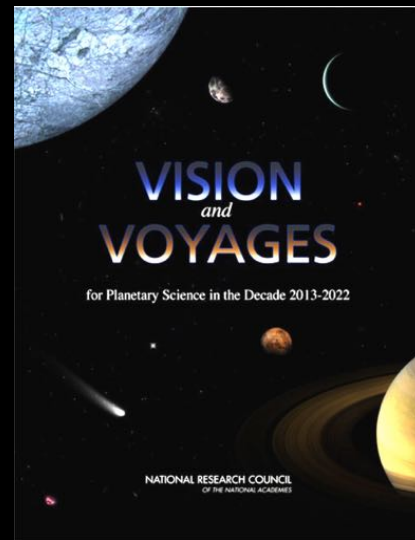
2007 – 2016

Heliophysics



2012 – 2021

Planetary



2013 – 2022

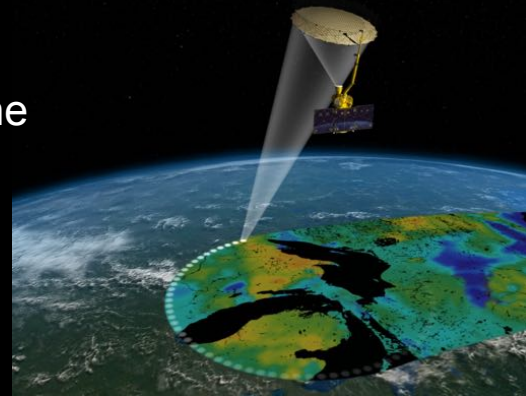
Organized by the National Academies on behalf of NASA establishing USA national priorities for scientific observations, as identified by the community, within a 10-year time frame

SMD Technology Overview

Nearly all of SMD's missions introduce new capabilities and push the state of the art in science instruments or platform technologies

Strategic technology investments must be coordinated across the Agency and are critical for the success of future missions

The SMD Technology Federation was established to provide the necessary cross-Agency coordination and to provide advice to the SMD Associate Administrator



**SMD
Technology
Federation**

Space Technology
Mission Directorate

SMD Chief Technologist

Office of Chief
Technologist

Heliophysics

Planetary

Earth

Astrophysics

Glenn

Ames

Goddard

JPL

Kennedy

Langley

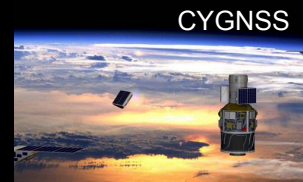
Marshall

NASA Center Chief Technologists

Overview of SMD Technology Programs

Program Name	FY16 Budget (approx, millions)
Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO)	\$6.7
Maturation of Instruments for Solar System Exploration (MatisSE)	\$14.3
Mars Technology	\$5.0
Icy Satellites Surface Technology	\$25.0
Advanced Technology	\$36.0
Advanced Power Systems	\$26.7
Planetary Science and Technology Through Analog Research	\$5.0
Heliophysics - Technology and Instrument Development for Science (H-TiDeS)	\$15.0
Instrument Incubator (IIP)	\$28.3
Advanced Component Technology (ACT)	\$6.5
In-Space Validation of Earth Science Technologies (InVEST)	\$9.5
Advanced Information Systems Technology (AIST)	\$14.3
Astrophysics Research and Analysis Program (APRA), see note below	\$46.2
Strategic Astrophysics Technology (SAT)	\$18.9
Nancy Grace Roman Technology Fellowships	\$1.4
Total SMD Technology Programs	\$258.8
APRA includes approximately 50% from balloons & sounding rocket programs	

Technology programs enable competed and strategic missions



Planetary Science Technology Programs

Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO, ~\$6.7M/yr)

- Low-TRL technologies
- Funds instrument feasibility studies, concept formation, proof-of-concept instruments, and advanced component technology.

Maturation of Instruments for Solar System Exploration (MatISSE, \$14.3M/yr)

- Mid-TRL technologies
- Enables timely and efficient infusion of technology into planetary science missions.

Planetary Science and Technology through Analog Research (PSTAR, ~\$5M/yr)

- Technologies that support science investigations
- Focus on identification of life

Technology Priorities		
PICASSO (Low TRL)	MatISSE (Mid TRL)	PSTAR
Miniaturization, low power, passively-cooled for all PSD instruments, particularly <i>in situ</i>		Sample acquisition and handling techniques
Low mass, miniature LIDARS and RADARS		Sample manipulation
Advanced, miniature sub-millimeter spectrometers		Mobile science platforms
Novel life detection instruments		Autonomous operations
Outer planet probe instruments		Self-contained deployment systems
High resolution UV spectrometers		Intelligent systems, human/robotic interfaces

Outer Planets Capabilities Assessment

Technology	Near-Term Missions				Mid-Term Missions				Far-Term Missions		
	Europa Flyby	Europa Lander	Titan Lander Discovery	Saturn Probe	Uranus Orbiter & Probe	Titan Saturn System	Europa Advanced Lander	Io Observer	Enceladus Plume	Pluto Orbiter & Lander	Neptune Orbiter & Probe
In-Space Propulsion	TRL 6									Low TRL; major investment needed	Mid-TRL; major investment needed
Aerocapture / Aeroassist											Mid-TRL; major investment needed
Entry											High TRL w/ funding
Descent and Deployment											
Landing											
Aerial Platforms											
Landers - Short Duration											
Landers - Long Duration											
Mobile Platform											
Planetary Protection											
Energy Storage - Batteries											
Energy Generation - Solar											
Energy Generation - Radioisotope Power											
Energy Generation - Alternative Sources											
Thermal Control - Passive											
Thermal Control - Active											
Rad Hard Electronics											
Cold Temperature Mechanisms											
Cold Temperature Electronics											
Communications											
Autonomous Operations											
Guidance, Navigation, and Control											
Remote Sensing - Active											
Remote Sensing - Passive											
Probe - Aerial Platform											
In Situ Surface - Short Duration											
In Situ Surface - Long Duration - Geophysical											
Sampling											
In Situ Surface - Long Duration - Mobile Laboratory											



TRL 6



High TRL w/
funding



High TRL;
limited funding,
development



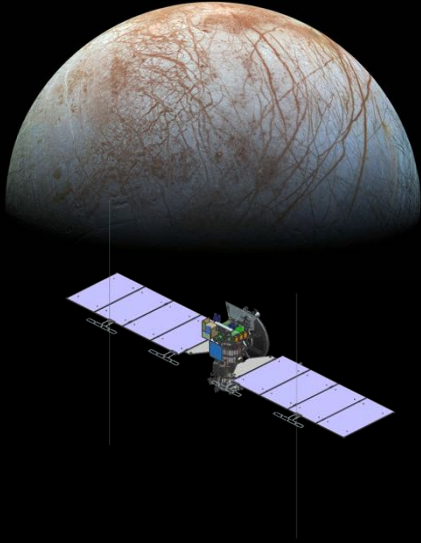
Mid-TRL; major
investment
needed



Low TRL; major
investment
needed

Planetary Science - Technology Trends

Immediate need - augmentation of Europa mission(s)



Planetary Science Technology Working Group assessing currently-identified technology gaps and will make recommendations for near-term investments

Early Mission Technologies

- Entry, Descent, Landing
- Landers - Short Duration
- Battery Storage
- Passive Thermal Control
- Radiation Hardened Electronics
- Cold Temperature Mechanisms
- Autonomy
- Guidance, Navigation, and Control
- In Situ Instruments
- Planetary Protection

Advanced Mission Technologies

- Entry, Descent, Landing
- Landers - Long Duration
- Battery Storage
- Passive Thermal Control
- Radiation Hardened Electronics
- Cold Temperature Mechanisms
- Autonomy
- Guidance, Navigation, and Control
- In Situ Instruments
- Planetary Protection
- Mobile Surface Platforms
- Radioisotope Power
- Cold Temperature Electronics
- Communications
- In Situ Surface - Suborbital Platforms

Alternative Paradigms for Enabling Science

- NASA budget constraints are limiting the cadence of new missions
- Cost and risk increase due to the exaggerated impact of the potential loss of a single mission, likely delaying science return
- Recent advances in miniaturization of instruments and platforms may ease the cycle of larger and fewer expensive missions, where appropriate, while still achieving the science requirements

Anticipated Benefits of Future SMD Small Sat Science Missions

- Lower costs
- More rapid development
- Higher risk tolerance
- Standardized launch interfaces
- “Build-test-fly” approach possible
- Lower barriers to entry for universities and small businesses
- Greater use of off-the-shelf components
- Possibilities for unique applications (i.e., constellations)



LandSat 8

Launch Mass: 2,071 kg

Instruments: Operational Land Imager (9 bands + panchromatic) and Thermal Infrared Sensor (2 bands)

Spectral Resolution: 15-100 meters (pending frequency)

Development to Launch: 2002 - 2013

Manufacturers: GSFC, Ball Aerospace, Orbital Sciences

Spectrum of Satellite Development

SMD/STMD Studies Focus on Decadal Science from U-Class & ESPA-Class



U-Class (CubeSat) / MicroSat

CP-6

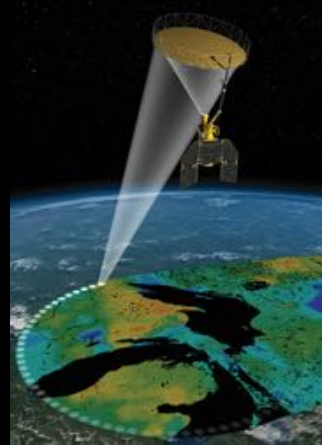
10 – 50 cm (linear)
1 – 100 kg
5 – 50 W
\$1 – 30 million (2015)



MiniSat / ESPA-Class

LCROSS

2 meters (linear)
585 kg (dry mass)
600 W
\$79 million (2009)



Medium-Class

SMAP

9.7 meters (linear)
944 kg
550 W (radar peak)
\$916 million (2015)



Large-Class

SOHO

4.3 meters (linear)
1850 kg
1,500 W
\$1,100 million (1995)



Flagship-Class

Aura

17.37 meters (linear)
2,967 kg
4,600 W
\$785 million (2004)

Confronting the Barriers

Platform Technology Gaps

Addressed by STMD along with partners in academia and private industry

- Power
- Thermal control
- High speed communications
- Precision pointing
- Propulsion
- On-board processing
- Ground system architectures and standards
- “Swarm” technologies

Instrument Technology Gaps

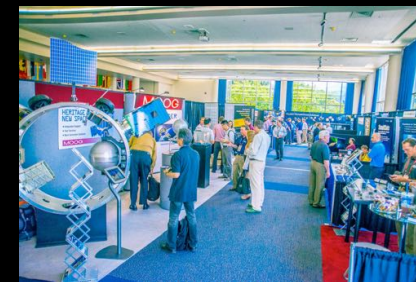
Addressed by SMD along with partners in academia and private industry

Miniaturization of science instruments in likely feasible areas¹:

Sounders, imagers, radiometers, gravity instruments, magnetic field instruments, ocean color instruments, radars, chemical and biological sensors

Studies

- SMD-led NRC study on Achieving Science Goals Through CubeSats
- Internal SMD small satellite studies (Earth, Heliophysics completed)



¹: Per Selva and Krejci “A survey and assessment of capabilities of cubesats for Earth observation”, Acta Astronautica, 2012.

SMD/STMD Study of New Opportunities for Low-Cost Science Instruments, Platforms, and Mission Architectures

Joint SMD/STMD study initiated in February 2015 with key goals:

- Investigate current paradigm shifts in the miniaturization of science instruments and disruptive small satellite platform technologies
- Determine the potential for novel approaches that could break the cycle of “larger but fewer” expensive missions
- Identify key SMD science measurement requirements that could be satisfied through such paradigms
- Identify technology gaps that could be addressed through solicitations such that barriers to alternative paths are removed



Study Timeline	
Earth Science	Spring / Summer 2015
Heliophysics	Summer / Fall 2015
Planetary Science	2016

Study Results - Earth Science

Classifying potential instrument/measurement options from SmallSat Study

Mission	SmallSat Instrument	SmallSat Capable	Architecture	Key Technologies
CloudSat	Cloud Profiling Radar	Potentially Yes: ESPA+	Constellation	2m deployable antenna, high power system
GACM	UV/VIS/SWIR Spectrometer, microwave limb sounder	Yes: 12U to ESPA	Constellation	Differential absorption LIDAR
GEO-CAPE	UV/VIS/NIR Wide Area and event imaging spectrometer, TIR radiometer	Yes: Hosted Payload, Propulsive ESPA	Constellation	UV-NIR wide field imaging spectrometer
GPM Core	3D dual precipitation radar (Ka/Ku) with multichannel microwave imager	Yes: Ka-band/microwave No: Ku-band radar	Constellation	Ku-band narrow pulse precipitation radar
HyspIRI	Visible-shortwave infrared spectrometer and thermal infrared imager	Yes: Pegasus Mini Satellites	Instruments on separate platforms	Compact Dyson spectrometer
NISAR	Circularly Polarized SAR (CP-SAR) at L-band	Probably Not: ESPA	Repeat Pass or Constellation	2m x 5m deployable antenna
SMAP	Wide swath shared aperture radar/radiometer	No	N/A	Wide swath shared aperture measurement
SWOT	Long baseline Ka-band radar	Probably Not: ESPA+	Repeat Pass or Constellation	Precision formation flying, on-board interferometry

Decadal-Class Science Measurement Requirements

Comparing measurement drivers and alternative approaches - Earth Science

Mission	Driving Requirement	Alternative Architecture	Enabling Technology
QuickScat	Ocean surface wind speed and direction Scatterometer: 1,800 km swath, wind speed 3-20 m/s and 25 km wind vector resolution	GPS reflectometry constellation architecture for frequent revisits (e.g. CYGNSS)	Delay Doppler mapping instruments (GPS receivers)
HyspIRI	Surface composition & ecosystem health VSWIR: 60m spatial resolution, 19-day revisit TIR: 60m spatial resolution, 5-day revisit	Separate spacecraft designed to SmallSat Pegasus configuration (e.g. Dyson-VSWIR)	Compact Dyson imaging spectrometer design
GPM	3D precipitation structure Ka-band (35.5 GHz) and Ku-band (13.6 GHz) precipitation radars at 125 km and 245 km swaths	Ka-band constellation alternative measurement approach (e.g. RainCube)	Ka-band deployable antenna and pulse compression method
PATH	All-weather temp/humidity soundings Spectrometric observations of microwave emission in 50-70, 118, 183 GHz lines	Radiometer and/or GPSRO constellation architecture (e.g. Mystic Winds / MiRaTA)	Compact MWIR design, radiometers, and GPS receivers
3D Winds	3D Tropospheric winds 2-micron and ultraviolet Doppler wind lidar	No immediate alternative	Laser SWaP and duty cycle capabilities must advance

Alternative approaches either provide an **equivalent measurement**, **no clear alternative**, or a **reduced scope measurement** that may satisfy specific requirements

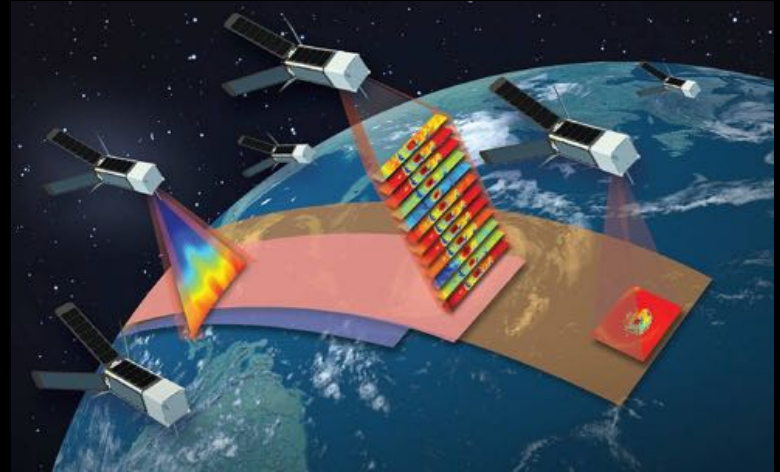
TROPICS

First high-revisit microwave observations of temperature, precipitation, humidity

Correlates precipitation structure evolution, including diurnal cycle, to the evolution of the upper-level wave core and intensity changes

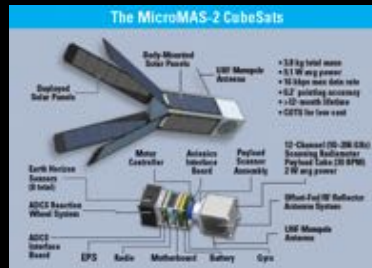
Relates the occurrence of intense precipitation cores (convective bursts) to storm intensity evolution

Relates retrieved environmental moisture measurements to coincident measures of storm structure



MicroMAS-2 CubeSat

Each MicroMAS-2 CubeSat is a dual-spinning 3U CubeSat equipped with a 12-channel passive microwave spectrometer



Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of SmallSats (TROPICS)

Launch Mass: 3.6 kg (per each of 12 satellites)

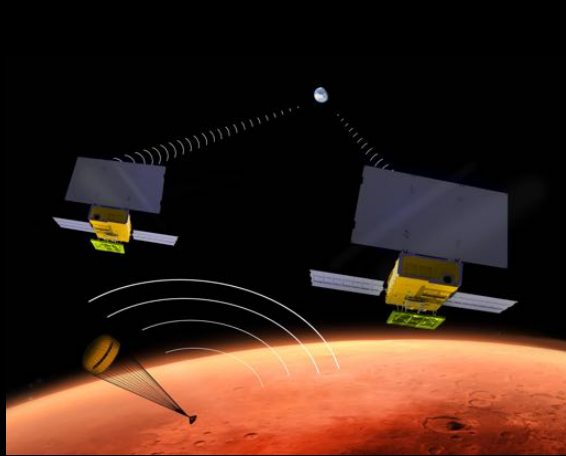
Instrument: Microwave spectrometer

Design: 12 identical 3U CubeSats

Development to Launch: 2016 - 2019

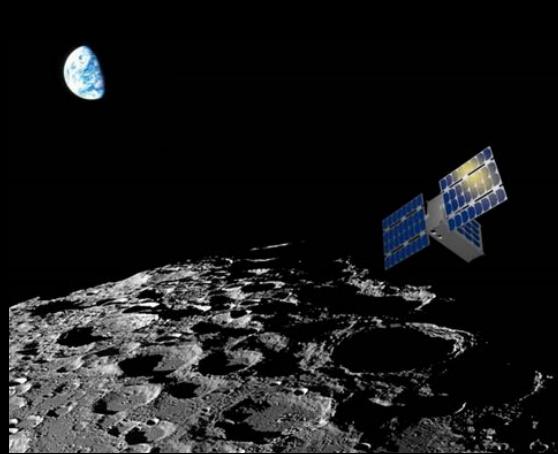
Manufacturers: Massachusetts Institute of Technology

2015 Technology Highlights - Planetary Science



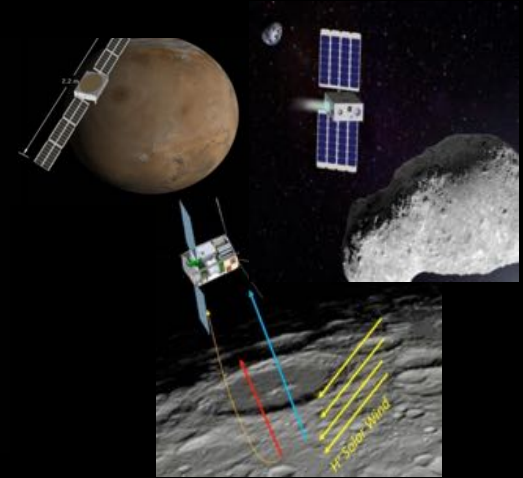
MarCO

Two 6U CubeSats, flying with the InSight mission to Mars, to act as real-time EDL telecom relays



LunaH-Map

6U CubeSat that will fly on the Earth-Moon 1 (EM1) to sense the presence of hydrogen in craters and dark shadows on the Moon



CubeSat Study Missions

Mars Micro Orbiter, Hydrogen Albedo Lunar Orbiter (HALO), Diminutive Asteroid Visitor using Ion Drive (DAVID)

Joint SMD/STMD Study - Planetary Science

Mission concepts for small satellites are needed

Study requires additional mission concepts that involve small spacecraft

SMD is requesting input from the Assessment Groups to help define notional requirements for small spacecraft -the following survey is being provided to all of the AGs

Science Application	Brief Description
NASA Relevance	Link science application to the SMD Decadal Survey science priorities, HEOMD (strategic knowledge gaps), Planetary Defense.
Nature of Investigation	Detail the type of measurement to be performed (in a few sentences).
Targets	List of planetary bodies at which the investigation is applicable or sought.
Instrument	Describe the type of instrument and performance sought for the investigation.
Instrument Availability?	Indicate if instrument already exists, under development (which program?), not available, or if availability is unknown.
Type of Architecture and Vantage Point	Indicate if the investigation is performed in situ or remote; precise if it is best accomplished in a mother-daughter architecture, constellations, or single (independent) asset.
Novel/Unique Contribution	Explain why CubeSats or SmallSats are uniquely placed to perform the proposed investigation.
Challenges	Detail challenges you are aware of (e.g., resources, attitude control,etc.) for implementing the investigation in a CubeSat/SmallSat.

CubeSat Concepts for Small Body Missions

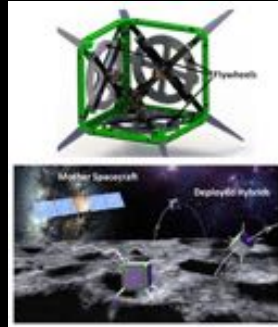
Examples from SBAG small spacecraft survey



Swarm Flyby Gravimetry

Justin Atchison/Johns Hopkins University
NIAC 2015 Phase II

- Estimate an asteroid's gravity field and infer its underlying composition and structure.
- 6U P-Pod sized simple probes ejected from an orbiter. Two types: diffusely reflective spheres tracked by telescope, and spherical corner-cube retro-reflectors tracked by lidar.
- IR tracking is limited by available on-board energy storage and the quality of infrared focal plane arrays, and RF beacons require low cost, ultra-stable oscillator circuits. Low cost/mass/volume/power consumption of spacecraft pointing technologies would be beneficial.



Spacecraft/Rover Hybrids for the Exploration of Small Solar System Bodies

Marco Pavone/Stanford
NIAC 2014 Phase II

- Systematic in-situ exploration.
- 8U-sized hybrid mobility platforms actuated by internal flywheels. Each carries an imaging camera, microscope, and APXS instrument. The platforms are scalable from 1U to 27U. The lifetime of the platforms is limited by the battery – improved primary battery capacity and/or lower power consumption instruments would extend the mission range.



Seismic Exploration of Small Bodies

Jeffrey Plescia/JHU
NIAC 2015 Phase I

- Understand the interior structure of small bodies.
- CubeSats deploy micro-seismometers on the surface. Each independently detonates to provide an energy source for the remaining others to detect.
- Active seismology experiment would provide the seismic velocity of the interior across some number of ray paths and thus resolve whether asteroids are rubble piles or have solid interiors with a fragmental surface layer.

New Solicitation: Planetary Science Deep Space SmallSat Studies

Funding will be provided for formal mission design studies

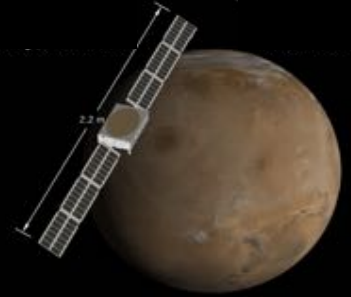
Overview: Approximately \$3M to be made available to fund 6-15 6-month studies

Goals:

- Acquire detailed concept studies for deep space Planetary Science missions that can be accomplished with small spacecraft
- Stimulate creativity in the community for science enabled by small, low cost deep space missions (\$10M - \$100M) - proposals should push state of the art

Proposed investigations should be responsive to the goals of NASA's Planetary Science Division

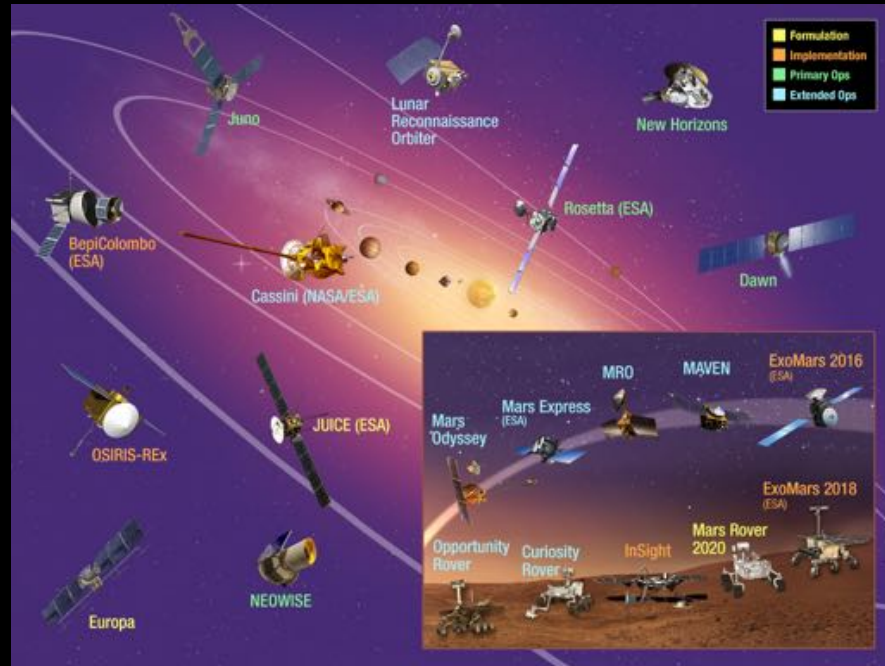
Official announcement will be made by the Planetary Science Division through ROSES (POC: William Cook)



Mars Micro Orbiter
SIMPLEX CubeSat
Michael Malin, PI

Backups

Planetary Science



Missions in Formulation / Operating



Strategic Missions (Notional)

Current Findings and Observations

Constellations, platform diversity, and dedicated launch

For Earth observations, given instrument duty cycles, power requirements, data downlink needs, and reliability, most Decadal-like science (from SmallSats) may require flight systems larger than CubeSats likely in the 50 kg to ESPA-class regime or higher

Constellation mission designs are a growing trend that will enable more frequent observations with greater coverage and the ability to support sustained continuity measurements at reasonable costs over time

Dedicated launch capabilities that can support a variety of small satellite systems will need to continue to mature



Virgin Galactic Launcher One

Launch Mass: 225 kg (LEO) or 125 kg (SSO)

Accommodation: ESPA-Class envelope

Cost: Less than \$10 million per flight

Manufacturers: Virgin Galactic