National Aeronautics and Space Administration

Science Mission Directorate
Strategic Technology - CubeSats

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A Balanced Approach to Achieving SMD Science
SCIENCE MISSION DIRECTORATE
By the Numbers

Spacecraft
102 missions*
85 spacecraft

CubeSats
12 science missions*
11 technology demonstrations

Balloon Payloads
13 science payloads in FY17
13 piggyback/educational payloads in FY17

Sounding Rocket Flights
14 science missions in FY17
3 technology/educational missions in FY17

Earth-Based Investigations
25 major airborne missions
8 global networks

Technology Development
~$400M invested annually

Research
10,000$^+$ U.S. scientists funded
3,000$^+$ competitively selected awards
~$600M awarded annually

*114 space-based missions

October 26, 2016

SCIENCE MISSION DIRECTORATE

114 Space-Based Science Missions

Formulation (9)

- **WFIRST**

- *HOSTED (Maia)*
- ***JPSS-2** (RBI, OMPS-L)*
- *Landsat-9*
- **PACE**
- **TROPICS (12) ❒**

- **AIDA-DART**
- **Europa**
- *JUICE (JEPI, RIME, UVS)*

Implementation (42)

- **CeRES ❒**
- **CUPID ❒**
- **CuSP ❒**
- *DSX (SET-1)*
- **ELFIN ❒**
- *HOSTED (GOLD)*
- **ICON**
- *SOC (SoloHI, HIS)*
- **Solar Probe Plus**
- **SORTIE ❒**
- **TBEx (2) ❒**

- *Euclid (SCS)*
- **HaloSat ❒**
- ISS (CREAM)
- ISS (NICER)
- **TESS**
- **Webb**

- **CYGNSS (8)**
- **GRACE-FO (2)**
- *HOSTED (TEMPO)*
- **ICESat-2**
- ISS (ECOSTRESS)
- ISS (GEDI)
- ISS (LIS)
- ISS (OCO-3)
- ISS (SAGE-III)
- ISS (TSIS-1)
- *NISAR (L-Band SAR)*
- *SWOT (KaRIn, AMR)*

- *BepiColombo (Strofio)*
- *ExoMars 2020 (MOMA)*
- **InSight (MarCO (2) ❒)**
- **LunaH-Map ❒**
- **Mars 2020**
- **Q-PACE ❒**

- ***GOES-R, -S, -T, -U***
- ***JPSS-1***
- *MetOp-C (AMSU, AVHRR, SEM)*

Primary Ops (16)

- **MinXSS ❒**
- **MMS (4)**

- *LISA Pathfinder (DRS)*
- SOFIA

- ***DSCOVR** (NISTAR, EPIC)*
- **GPM**
- ISS (CATS)
- ISS (RapidScat)
- ***Jason-3** (AMR, GPSP)*
- *Landsat-8*
- **OCO-2**
- **SMAP**

- *ExoMars 2016 (Electra)*
- **Juno**
- **New Horizons**
- **OSIRIS-Rex**

Extended Ops (47)

- **ACE**
- **AIM**
- *Geotail (EPIC, CPI)*
- *Hinode (XRT, EIS, SOT/FPP)*
- **IBEX**
- **IRIS**
- **RHESSI**
- **SDO**
- *SOHO (LASCO)*
- **STEREO (2)**
- **THEMIS-Artemis (5)**
- **TIMED**
- **TWINS A&B (2)**
- **Van Allen Probes (2)**
- **Voyager (2)**
- **Wind**

- **Chandra**
- **Fermi**
- **Hubble**
- **Kepler/K2**
- **NuSTAR**
- **Spitzer**
- **Swift**
- *XMM-Newton*

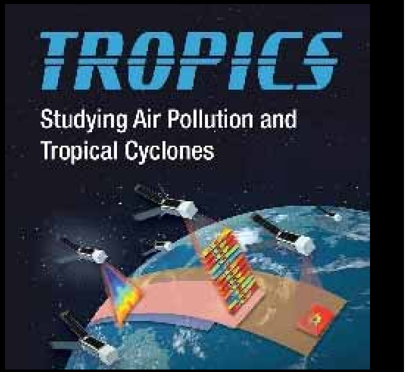
- **Aqua**
- **Aura**
- *CALIPSO (CALIOP)*
- **CloudSat**
- **EO-1**
- **GRACE (2)**
- **LAGEOS (2)**
- *Landsat-7*
- *OSTM/Jason-2 (AMR, GPSP, LRA)*
- **QuikSCAT**
- **SORCE**
- *Suomi NPP (OMPS-L Suite)*
- **Terra**

- **Cassini**
- **Dawn**
- **LRO**
- *Mars Express (ASPERA-3)*
- **Mars Odyssey**
- **MAVEN**
- **MER Opportunity**
- **MRO**
- **MSL Curiosity**
- **NEOWISE**

SMD Spacecraft
Non-SMD Spacecraft (SMD instrument)
❒ indicates CubeSat science mission

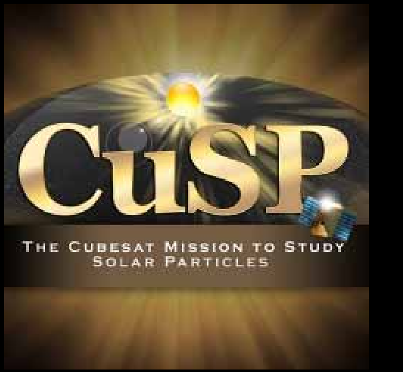
🟧 **HELIOPHYSICS**
🟩 **EARTH SCIENCE**
🟥 **PLANETARY SCIENCE**
🟦 **ASTROPHYSICS**
⬜ **REIMBURSABLES**

CubeSat Science Missions



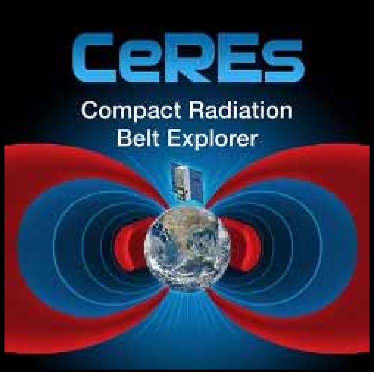
	PI-Led	PI-Led	PI-Led	Venture Class PI-Led
Spacecraft Size	3U CubeSat	6U CubeSat	(2) 6U CubeSats	(12) 3U CubeSats
Science Objective	Study solar emissions that can affect Earth's communications systems	Study sources of wave-like plasma perturbations in the ionosphere	Provide real-time data relay during InSight entry, descent, and landing	High-resolution sounding within hurricane eyes
Expected Launch Date	Dec. 2015	FY17	FY18	FY19

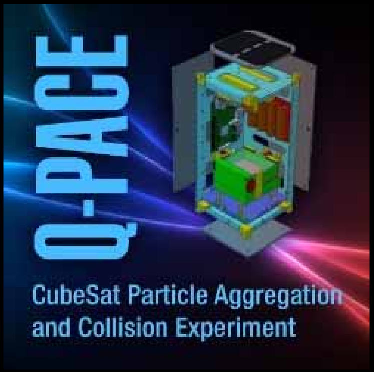
CubeSat Science Missions

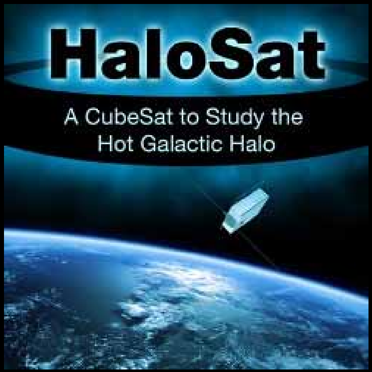


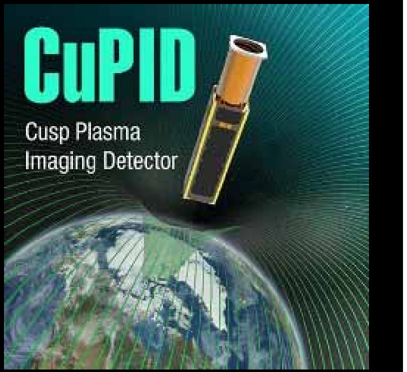
	H-TIDeS PI-Led	H-TIDeS PI-Led	SIMPLEx PI-Led	H-TIDeS PI-Led
Spacecraft Size	3U CubeSat	(2) 3U CubeSats	6U CubeSat	6U CubeSat
Science Objective	Study dominant wave-loss mechanism of relativistic “killer” electrons	Study tropical weather relationship to ionospheric bubbles	Map the water content at lunar South Pole	Study solar particles and fields that affect space weather
Expected Launch Date	FY17	FY17	FY18	FY18

CubeSat Science Missions





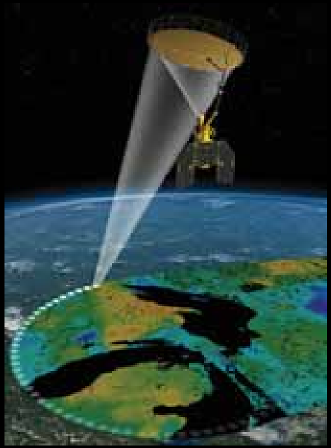
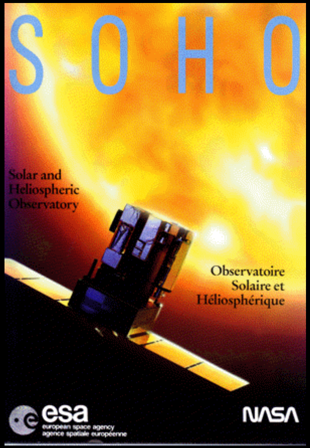
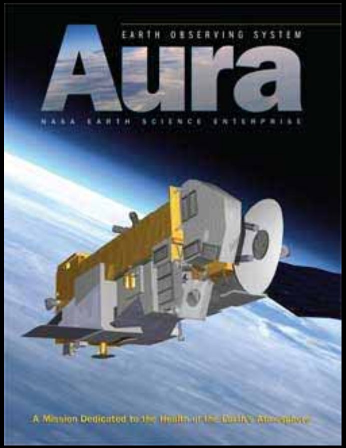




	H-TIDeS PI-Led	SIMPLEx PI-Led	APRA PI-Led	H-TIDeS PI-Led
Spacecraft Size	3U CubeSat	2U CubeSat	6U CubeSat	3U CubeSat
Science Objective	Study how electrons are energized and lost from the radiation belts	Explore fundamental properties of particle collisions	Study the hot gas associated with the Milky Way	Image the solar wind around Earth, planets, and the moon
Expected Launch Date	FY17	FY17	FY18	FY19

Spectrum of Satellite Development

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

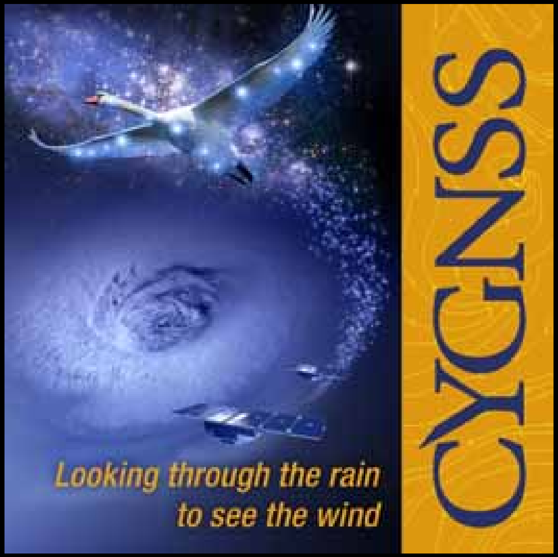
				
U-Class (CubeSat) / MicroSat	MiniSat / ESPA-Class	Medium-Class	Large-Class	Flagship-Class
CP-6	LCROSS	SMAP	SOHO	Aura
10 – 50 cm (linear)	2 meters (linear)	9.7 meters (linear)	4.3 meters (linear)	17.37 meters (linear)
1 – 100 kg	585 kg (dry mass)	944 kg	1850 kg	2,967 kg
5 – 50 W	600 W	550 W (radar peak)	1,500 W	4,600 W
$1 – 30 million (2015)	$79 million (2009)	$916 million (2015)	$1,100 million (1995)	$785 million (2004)

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)



The Cyclone Global Navigation Satellite System (CYGNSS) use eight micro-satellites to probe the inner core of hurricanes to learn about their rapid intensification.

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 areas[1]:

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 Though CubeSats
- Internal SMD small satellite studies (Earth, Heliophysics completed)

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[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

Joint SMD/STMD Study

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

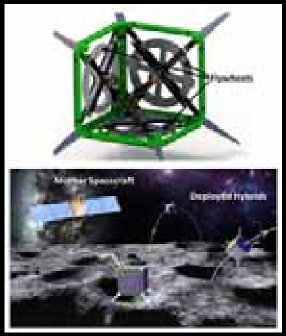
Science Applicaton	Brief Description
NASA Relevance	Link science application to the SMD Decadal Survey science priorities, HEOMD (strategic knowledge gaps), Planetary Defense.
Nature of Investigation	Detail the type of measurement to be performed (in a few sentences).
Targets	List of planetary bodies 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: currently funded NIAC studies

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 (PSDS^3)

Funding will be provided for formal mission concept 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

ROSES proposals were received Nov. 18 (POC: Carolyn Mercer)

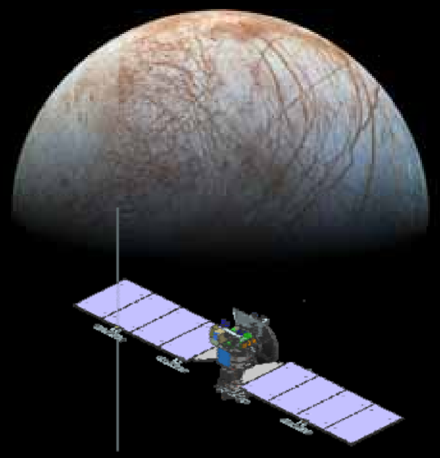
Venus Capabilities Assessment
(VEXAG technology plan 2014)

🟩 TRL 6
🟨 High TRL
🟧 Mid TRL
🟥 Low TRL

	Venus Applicable Technology	NEAR TERM MISSIONS							MID TERM MISSIONS				FAR TERM MISSIONS				
		Radar Orbiter	Remote Sensing Orbiter	Aerial Platform Sustained	Deep Probe	Multiple Shallow Probes	Multiple Shallow Sondes	Lander - Smooth Terrain	Lander - Rough Terrain	Lander - Long Duration	Multi Deep Probe	Multi Deep Sondes	Lander Network	Mobile Surface	Mobile Near Surface	Sample Return Clouds	Sample Return Surface
SYSTEM TECHNOLOGIES	Aerocapture															🟧	🟧
	Aerobraking	🟩	🟩														
	Entry			🟨	🟨	🟨		🟨	🟨	🟨	🟨		🟨	🟨	🟨	🟧	🟧
	Descent and Deployment			🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟥
	Landing at target object							🟩	🟨	🟨			🟩	🟧			🟥
	Aerial Platforms			🟩			🟩					🟨			🟧	🟧	🟥
	Landers - Short Duration							🟩	🟩								
	Landers - Long Duration									🟧			🟧				
	Mobile platform - surface, near surface													🟥	🟥		
	Ascent Vehicle															🟥	🟥
SUBSYSTEM TECHNOLOGIES	Energy Storage - Batteries	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟩	🟩	🟥	🟥	🟥		
	Power Generation - Solar	🟩	🟩	🟨													
	Power Generation - RPS									🟧			🟥	🟥	🟥		
	Thermal Control - Passive					🟩	🟩	🟩	🟧	🟧	🟧	🟧					🟥
	Thermal Control - Active												🟥	🟥	🟥		
	High Temp Mechanisms							🟨	🟨	🟧			🟥	🟥	🟥		🟥
	High Temp Electronics							🟩	🟩	🟧			🟥	🟥	🟥		🟥
	Communications			🟩	🟩	🟩	🟩	🟩	🟩	🟧			🟥	🟥	🟥		
	GN&C			🟩					🟧	🟧		🟧	🟥	🟥	🟥		
INSTRUMENT	Remote Sensing - Active	🟩	🟩														
	Remote Sensing - Passive	🟩	🟩														
	Probe - Aerial Platform			🟩	🟩	🟩	🟩				🟩	🟩				🟧	
	In Situ - Short Duration							🟨	🟨								🟧
	In Situ Surface - Long Duration - Geophysical									🟧			🟥				
	In Situ Surface - Long Duration - Mobile													🟥	🟥		

Planetary Science - Technology Trends

Technology Needed for Europa mission(s)



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

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

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

Questions?