NASA perspectives on Cubesats and Highlighted Activities

Briefing to Committee on Achieving Science Goals with CubeSats
NRC/Space Studies Board
June 22, 2015

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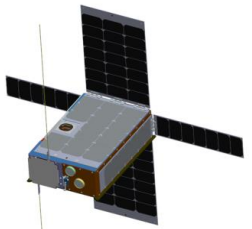
NRC/SSB CubeSat Briefing Agenda

- NASA CubeSat Activities
- NASA's Perspective for CubeSats
- Support to the CubeSat Community
  - Launch Services (HEOMD/CSLI)
  - Communications (HEOMD/SCaN)
  - Value-added mission support
- Technology – STMD
- Science – SMD
- Advocacy and Partnerships
- Addressing Requested Questions
- Summary

NASA CubeSat Activities

NASA promotes CubeSat activities in the U.S. through management and close coordination of its program elements, to include:

- Conducting Earth and Space science investigations, and developing precursor instrument technologies for future science measurements. (SMD)
- Developing and demonstrating new small spacecraft technologies and capabilities for NASA's missions in science, exploration and space operations. (STMD)
- Fostering Innovation across NASA/community. (STMD)
- Providing launch opportunities to the U.S. CubeSat Community (academia, government, and non-profits). (HEOMD)
- Sponsoring missions to address strategic knowledge gaps for exploration. (HEOMD)
- Coordinating frequency management and licensing for all NASA related missions. (HEOMD-SCaN)
- Maintaining critical competencies at NASA Centers and providing hands-on experience for the NASA workforce. (All)
- Promoting strategic partnerships and value – added services.
- Promoting STEM and inspiring students through hands-on student flight research missions (All)



Small Satellite Technology Program / STMD

Scientific Research / SMD

Access to Space - CubeSat Launch Initiative (CSLI) HEOMD

NASA's Perspective for CubeSats

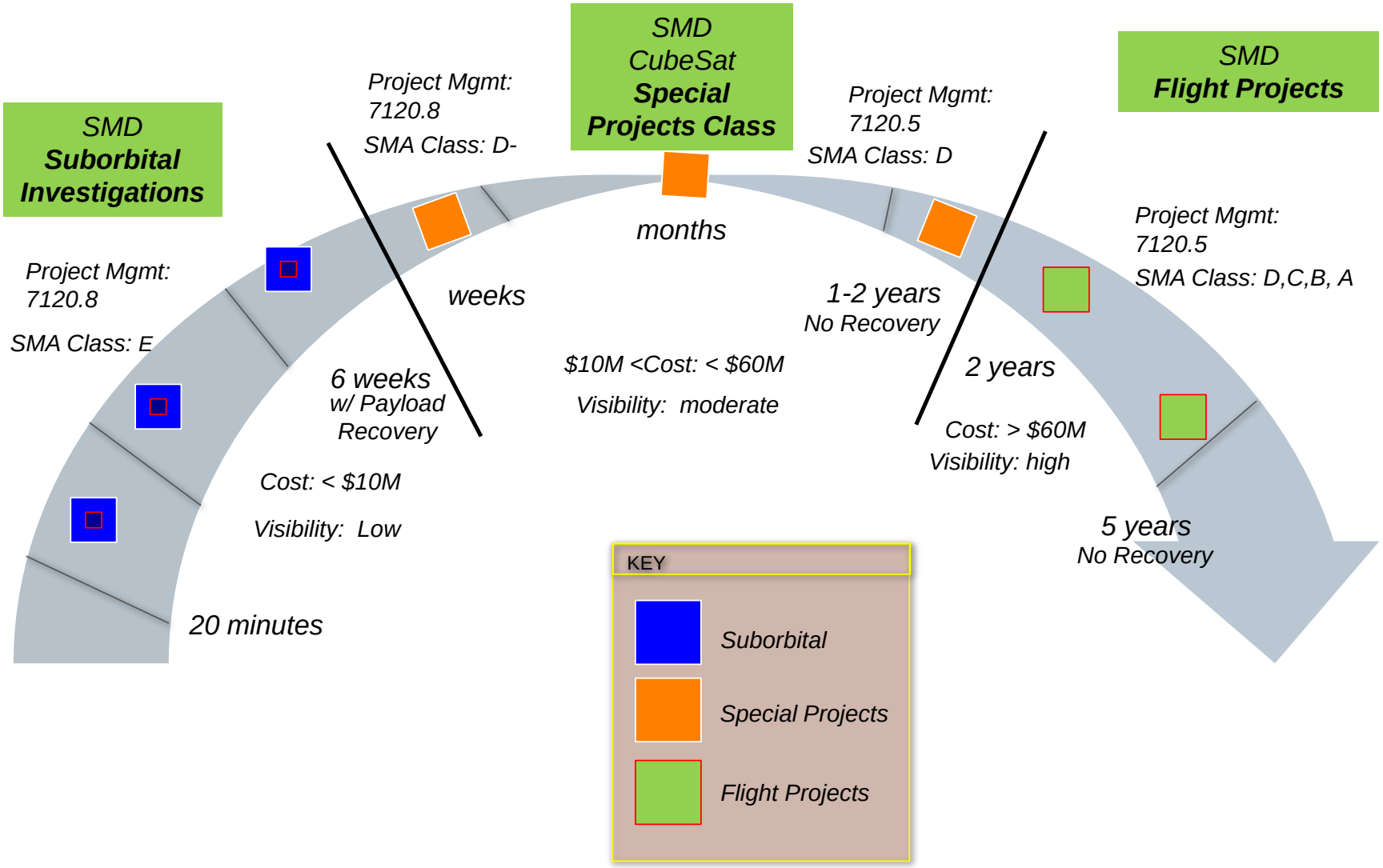
NASA recognizes the value of CubeSats as platforms for technology demonstration and hands-on training, and sees they offer the potential to address essential science goals.

SMD views cubesats as scalable platforms, from "suborbital-class" (sub-Class D) to flight project (Class D) platforms, enabling:

- Quick access to space for timely science measurements and to "fill the gap" for continuity of measurements between large flight projects.
- Flight demonstrations to mature technologies for infusion into mission-level programs
- Cubesats are small enough for the university researcher and fast enough for students to complete all phases of a project during their school career.

NASA wants to foster an environment of innovation for CubeSats, and wants insight into what near term investments are needed to ensure science value from CubeSats as a platform.

Payload - Cost / SMA Continuum

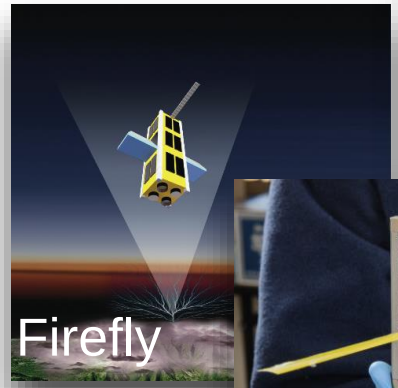


NASA Centers

Innovation Laboratories for Small Satellites

NASA is leveraging Center/JPL-led investments from IR&D and Center Innovation Funds

- These opportunities enable testbeds for small satellites in an open, innovative environment
- Projects are managed under technology procedural requirements, avoiding cumbersome flight project regulations
- Center investments provide a springboard for teams to propose to higher-valued science and technology solicitations



The Vision for Hands-On Training

"In my career as a scientist, astronaut, NASA's Chief Scientist, and AA/SMD, I often reflect back on the strength of the foundation upon which I was trained."

John M. Grunsfeld
AA/SMD, Astronaut

Suborbital (including CubeSats) projects provide students with the complete scientific experience, going from concept to hardware, observations, and scientific analysis of the results. All in a short time frame commensurate with their studies. These platforms not only enable quality science/technology investigations, but are also crucial as a training ground for the Scientists/Engineers who will be the project leaders of tomorrow.

NASA is providing launch services for funded cubesat missions

Launches at no cost to project through Cubesat Launch Initiative
- available to all NASA and other government sponsored cubesats also to educational institutions and non-profits through competition based on merit and relevance

ISS Deployments using commercial Nanoracks and JAXA deployers
- agreement with Nanoracks allows 3U for NASA out of each 48U

Some NASA-sponsored cubesat missions purchase commercial launch and integration services due to prior agreements, urgency, or special needs.

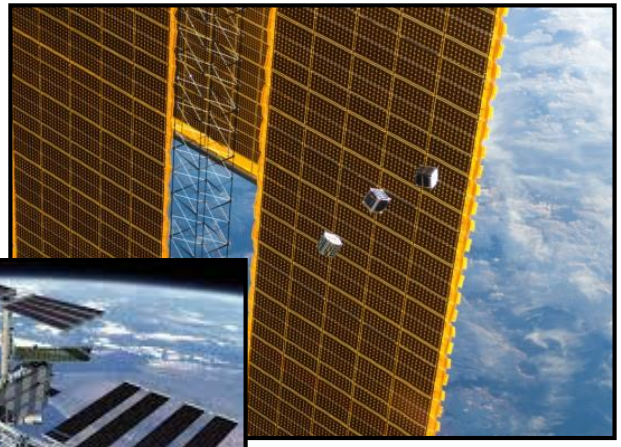
Launch opportunities for 11 Cubesats (6U) during the July 2018 Space Launch System/Exploration Mission-1.

CubeSat Launch Initiative

NASA's CubeSat Launch Initiative (CSLI) provides launch opportunities to educational, non-profit organizations and NASA Centers who build small satellite payloads that fly as auxiliary payloads on previously planned or commercial missions or as International Space Station deployments.

NASA
DoD
NRO

ISS



How It Works?

NASA Announcement of Opportunity

- NASA solicits proposals through an Announcement of Opportunity (AO)
- Educational Organizations, Non-Profits and NASA Centers submit proposed CubeSat Missions in response to AO

NASA Review

- A NASA Selection Committee made up of members of HEOMD (including the Launch Services Program), Space Technology Mission Directorate, Science Mission Directorate, and Education reviews proposals
- Selection Committee makes final recommendations on CubeSats
- NASA announces selection recommendations

Selectees Develop/Design/Build CubeSat

- Selectee builds satellite
- Selectee raises all funds necessary for satellite construction
- Selectee provides NASA completed satellite for integration for launch

NASA Assigns CubeSats to Manifested Launches

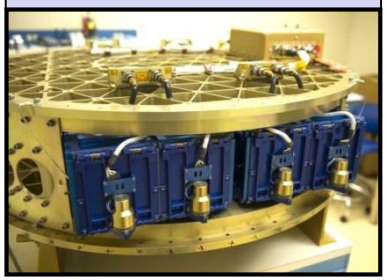
- NASA manifests CubeSat on available flights using excess lift capacity
- Cooperative Research and Development Agreement executed by NASA

Post Selection

CubeSats are Developed/Designed/Built

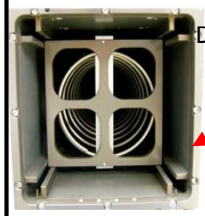
CubeSats are placed in P-POD

P-POD is integrated on the Launch Vehicle (LV)



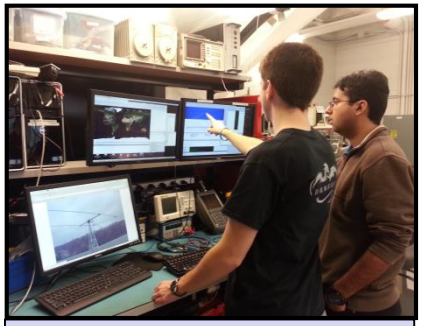
Mission Launches

Deployment spring and pusher plate



Signal Sent to LV, spring-loaded door is open, CubeSats deployed

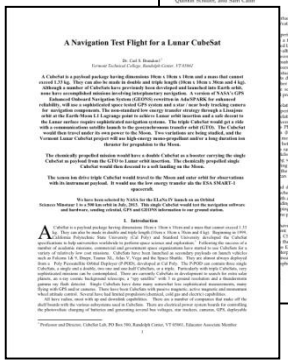
Students or Center track and operate CubeSat from Ground Station



CubeSat burns up on re-entry after completion of mission

Students or Center analyze data, write technical papers, provide results and data to NASA

Small Mission Accomplished by Students—Big Impact on Space Weather Research



A Navigation Test Flight for a Lunar CubeSat

Measures Of Success

CSLI Call #	# Proposals Received	# Adjusted Selected	# Available Manifest	# Manifested	# Launched	% Launched & Manifested
1st Selection	6	4	4		4	100%
CSLI - I	16	16	16	1	15	100%
CSLI - 2	25	12	11	1	10	92%
CSLI - 3	33	25	14	7	7	56%
CSLI - 4	34	19	7	4	1	26%
CSLI - 5	22	16	2	2	0	13%
CSLI - 6	22	13	1	0	0	0%
	158	**105**	**55**	**15**	**37**	**50%**

- **Adjusted Selected** - After adjustments made to selected CubeSats from recent survey of selectees, along with CubeSats chosen to fill open slots.
- **Available to Manifest** – CubeSats ready for final testing and integration; typically launch occurs ~ 9 months after the *Available to Manifest* date.
- ***Note: Of payloads ready to be manifested, 95% are launched or manifested***

Missions Launched

CubeSat Mission	Primary Mission	Launch Date	PPODs	Spacecraft	CubeSat Missions
ELaNa-I	Glory	Mar 4, 2011	1	3	3
ELaNa-II	NROL-39*	Dec 5, 2013	2	5	4
ELaNa-III	NPP	Oct 28, 2011	3	6	5
ELaNa-IV	ORS-3*	Nov 19, 2013	4	11	11
ELaNa-V	CRS SpX-3	Mar 16, 2014	4	5	5
ELaNa-VI	NROL-36*	Sep 13, 2012	3	4	4
ELaNa-VIII	ORB-3	Oct 21, 2014	Nanoracks	1	1
ELaNa-X	SMAP	Jan 30, 2015	3	4	3
ELaNa-XI	AFSPC-5	May 20, 2015	1	1	1
				TOTAL Launched	37

* Consistent with the National Space Policy of 2010, NASA has agreements with the national security space community to leverage our respective launch capabilities.

Manifest Schedule

CubeSat Mission	Primary Mission	NET Launch Date	PPODs	CubeSats
ELaNa-VII	ORS-4*	Jan 2016	2	2
ELaNa-XII	NROL-55*	Sept 25, 2015	2	4
ELaNa-IX	ORB-4	Nov 19, 2015	Nanoracks	3
ELaNa-XIII	FORMOSAT-5	FY 2016		2
ELaNa-XIV	JPSS-1	FY 2017	3	2
ELaNa-XV	STP-2	FY 2016		2
			TOTAL Manifested	15

* Consistent with the National Space Policy of 2010, NASA has agreements with the national security space community to leverage our respective launch capabilities.

Deep-space CubeSats: SLS EM-1 Secondary Payloads

SLS can accommodate 11 6U payloads on EM-1

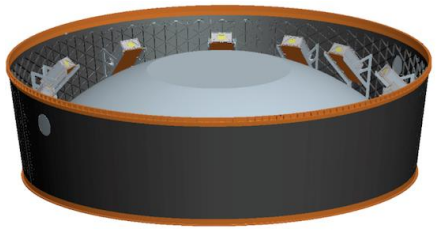
Commitments to Date:

- **AES CubeSats**
  - BioSentinel
  - Lunar Flashlight
  - NEA Scout
- **NextSTEP BAA Awardees**
  - Lockheed Martin Skyfire CubeSat
  - Morehead State University's Lunar IceCube
- **STMD Centennial Challenges initiated in November 2014**
- **Science Mission Directorate**
  - Heliophysics solicited through stand-alone announcement of opportunity
    - Proposals assessed for alignment with Heliophysics Decadal survey
    - 2 selected for further study (communication link analysis).
    - Down-Select to 1 mission (June, 2015)
  - Planetary Sciences solicited announcement of opportunity
    - SIMPLEx Proposals will be assessed for alignment with Planetary Decadal survey and PSD strategic goals.
    - Selection of 1 mission (august, 2015)

EM-1 Schedule

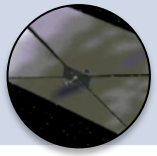
- **Payload Interface Agreement:** September, 2015
- **Payload Delivery to KSC:** February 1, 2018
- **SLS/EM-1 Launch Date:** July 15, 2018

Accommodations for secondary CubeSat payloads on the adapter between the Space Launch System upper stage and the Orion spacecraft.



AES EM-1 Secondary Payload Overview

- **HEOMD's Advanced Exploration Systems (AES) selected 3 concepts for further refinement toward a combined Mission Concept Review (MCR) and System Requirements Review (SRR) completed in August 2014**
  - All projects are proceeding towards Phase B design
- **Primary selection criteria:**
  - Relevance to Space Exploration Strategic Knowledge Gaps (SKGs)
  - Life cycle cost
  - Synergistic use of previously demonstrated technologies
  - Optimal use of available civil servant workforce
- **Completed a Non-Advocate Review of the Science Plan**

Payload *NASA Centers*	**Strategic Knowledge Gaps Addressed**	**Mission Concept**
BioSentinel ***ARC****/JSC* 	**Human health/performance in high-radiation space environments** • Fundamental effects on biological systems of ionizing radiation in space environments	Study radiation-induced DNA damage of live organisms in cis-lunar space; correlate with measurements on ISS and Earth
Lunar Flashlight ***JPL****/MSFC* 	**Lunar resource potential** • Quantity and distribution of water and other volatiles in lunar cold traps	Locate surface ice deposits in the Moon's permanently shadowed craters
Near Earth Asteroid (NEA) Scout ***MSFC****/JPL* 	**Human NEA mission target identification** • NEA size, rotation state (rate/pole position) **How to work on and interact with NEA surface** • NEA surface mechanical properties	Flyby/rendezvous and characterize one NEA that is representative of a potential human mission target

NASA Communication & Navigation Support

NASA's Space Communication and Navigation Program has initiated activities to support the small sat community including assessing long-term capabilities and potential collaborative activities

(a) NASA's twin MarCo cubesats, to be launched with the Mars Insight mission (Mar 2016) as the first deep space cubesat mission, will be supported by SCaN's Deep Space Network (DSN) and is in the planning and compatibility testing phase

(b) SCaN's Near Earth Network (NEN) is also planning to support several cubesat missions and several are in the planning and compatibility phase with launches in 2016

(c) SCaN is reviewing potential options to streamline some of the planning phase activities to keep costs minimal for small sat missions

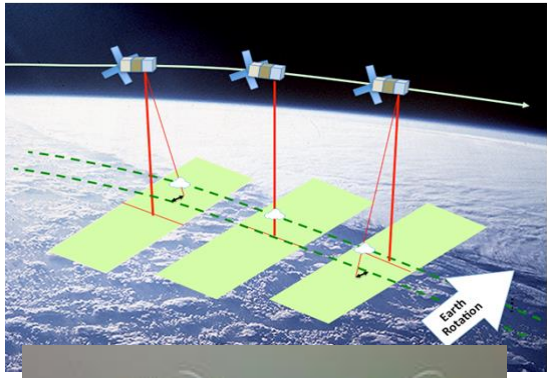
(d) SCaN is initiating a review of architecture and development needs, and such assessments will consider various options such as:

1) Work with the community to identify potential standardization of communication and navigation services across various networks;

2) Enhance the existing SCaN networks to support the potential large numbers of small sats and to contain costs;

3) Utilize commercial ground networks that are increasingly deploying systems to support small satellites.

CubeSat Community Support



Dynamic Ionosphere Cubesat Experiment (DICE) – Utah State, Embry-Riddle, Clemson

- Since 2008, NASA has partnered with the **National Science Foundation (NSF)** to facilitate the NSF Cubesat Program by assisting with mission support and institutional launch services to NSF-selected university cubesat teams.
- Provide a community Mission Planning Lab (MPL) for CubeSat proposals

  (16 MPL runs for teams in past 2 years)
- Provide mission management to PI team throughout project life cycle with programmatic, technical, and launch assistance;
- Recommend courses of action and help obtain government resources when requested.
  - Engineering support
  - Vehicle Integration support
  - Coordination with Range Safety and Environmental
  - Orbital Debris
  - Radio frequency allocation and licensing
  - Ground station support
  - Mission Operations

NASA Responded to Popularity of UHF for CubeSats Wallops UHF CubeSat Ground Station (not SCaN)

- **Specifications**
  - Beamwidth: 2.9 degrees
  - Frequency Range: 380 to 480 MHz
  - Secondary Frequency Band: X-Band available for future high data rate CubeSat communication
  - Antenna Main Beam Gain: 35 dBi
  - Diameter: 18.3 meters (60')
- **UHF Radar as a CubeSat Ground station**
  - 1st used with Utah State University Dynamic Ionosphere CubeSat Experiment (DICE)
    - Interference
    - Morehead added as a back-up
  - Cutting-Edge CubeSat communication over a government-licensed UHF frequency allocation that enables high data rates (3.0 Mbit/Sec)
  - Currently communicating with the Firefly and MicroMAS spacecraft
  - Slated for use for MiRaTA, Delingr, CeREs, HARP, IceCube, and many proposed CubeSats

Wallops UHF on left, S-Band on right

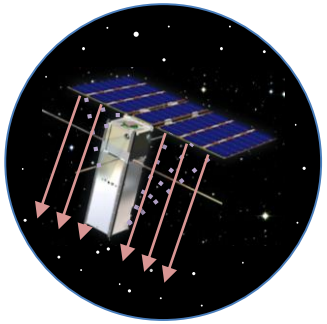
Morehead State University 21 Meter antenna

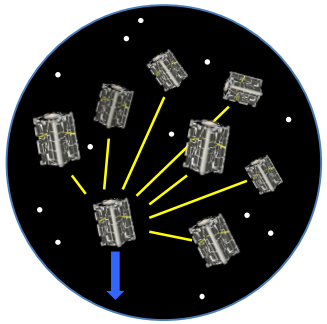
STMD/Small Spacecraft Technology

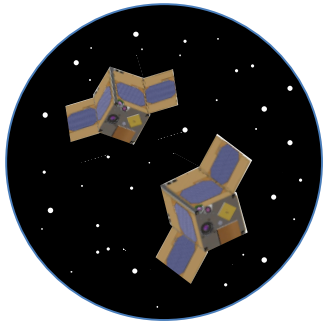
Small, Affordable, Rapid, & Transformative

Flight Demonstration Projects in:
Advanced Radio and Laser Communications
Formation Flight and Autonomous Docking
Smallsat swarms for space science missions
Low-cost satellite buses
Propulsion, simple de-orbit, Power, ADC

Implemented through:
Directed NASA projects
Contracts with private industry
University-NASA partnerships
Collaboration with SBIR and other programs

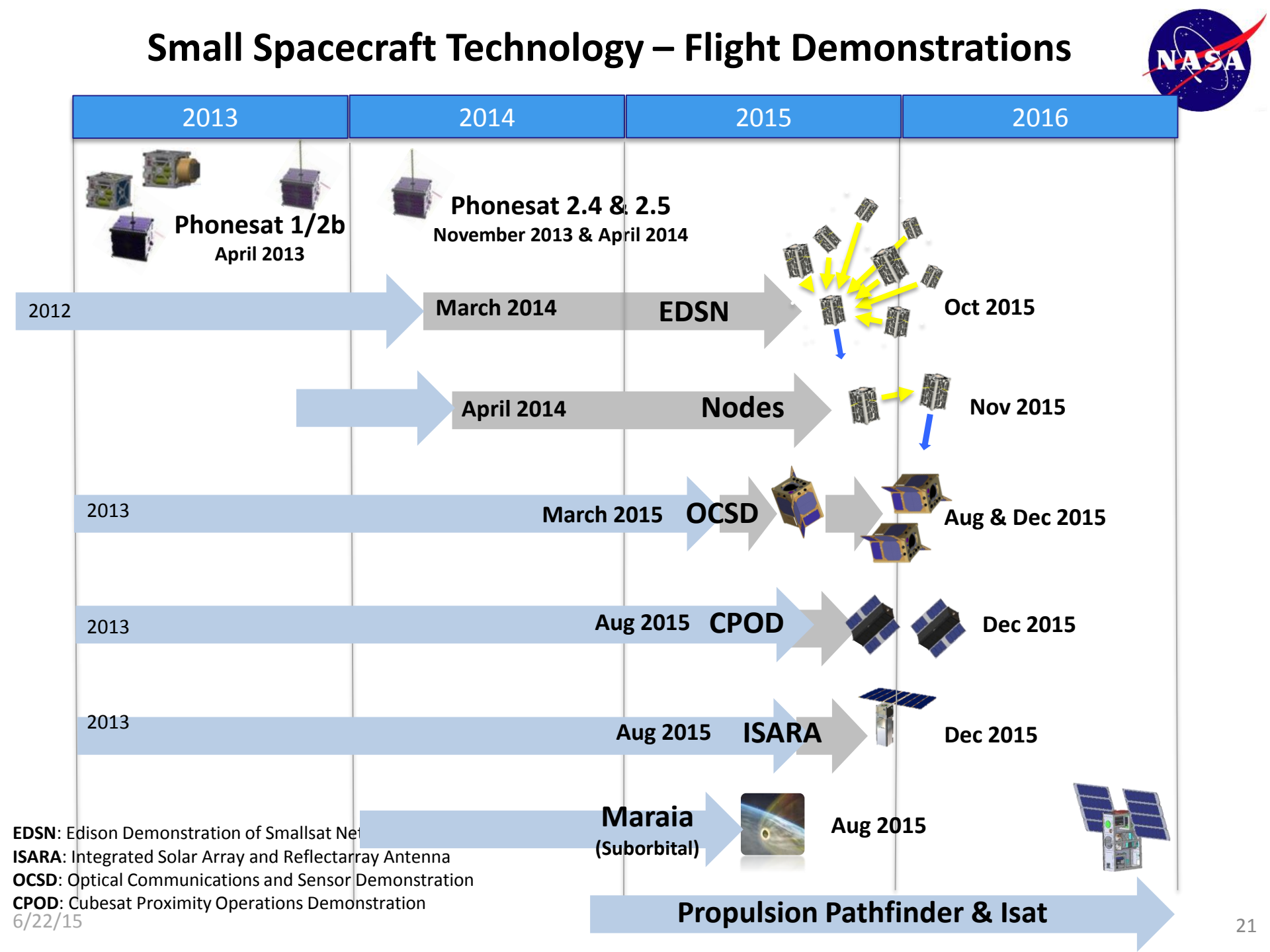






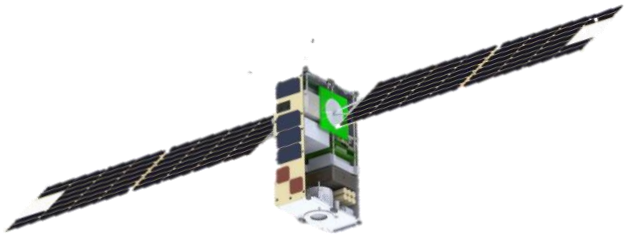
Five Phonesats flown in 2013-14
Seven demo missions planned for Aug 2015-Jan 2016
With 16 satellites and one suborbital capsule

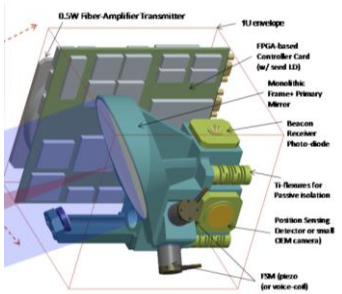
Small Spacecraft Technology – Flight Demonstrations



EDSN: Edison Demonstration of Smallsat Net
ISARA: Integrated Solar Array and Reflectarray Antenna
OCSD: Optical Communications and Sensor Demonstration
CPOD: Cubesat Proximity Operations Demonstration

SBIR – Deep Space Cubesat Technology





2014 Phase 1 Projects

COMMUNICATIONS AND NAVIGATION

Fibertek, Inc. - Herndon, VA
Innoflight, Inc. - San Diego, CA
ASTER Labs, Inc. - Shoreview, MN

POWER GENERATION

MicroLink Devices, Inc. - Niles, IL
Nanohmics, Inc. - Austin, TX

PROPULSION

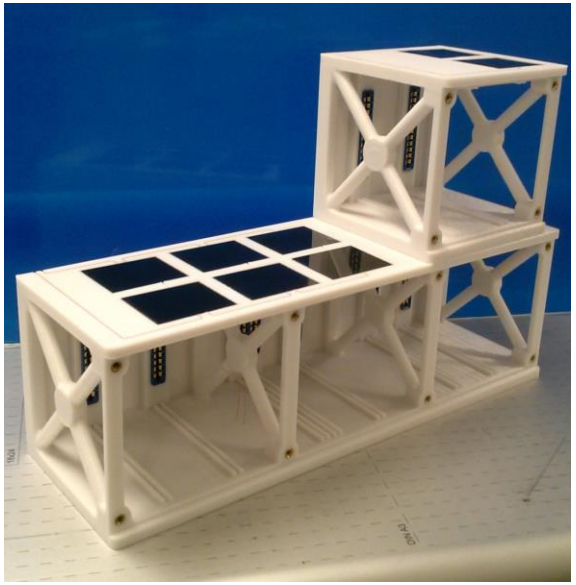
Altius Space Machines, Inc. - Louisville, CO
Aether Industries, LLC - Ann Arbor, MI

DEEP SPACE BUSES

ExoTerra Resource LLC - Lone Tree, CO
Busek Company Inc. - Natick, MA

STMD Smallsat Technology Partnerships

The Smallsat Technology Partnerships is an opportunity for college and university teams to develop and/or demonstrate small spacecraft technologies and capabilities for small spacecraft in collaboration with NASA researchers.
The solicitation link is at:
http://go.nasa.gov/1ICbBtO



3U Cubesat prototype with embedded copper wire and solar array (U of New Mexico, UT-El Paso & NASA Glenn)

Two year projects
- Up to $100,000 per year, per university
- Up to 1.0 FTE in NASA labor per year

13 Projects selected in 2013
- 17 universities
- 7 NASA Center partners

Two projects awarded NASA launch opportunities
- Montana State & NASA Goddard – radiation-hardened processor
- California State-Northridge & NASA JPL – advanced power system

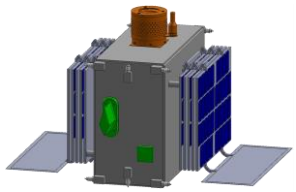
Annual solicitations planned starting in 2015

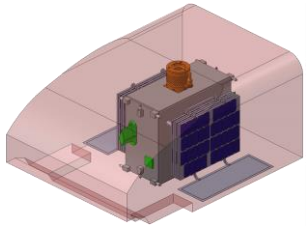
Small Spacecraft Deployments from ISS

Capability for deployment of larger small spacecraft has been developed

Deployment of Spinsat - November 28, 2014
A project of the Naval Research Lab

Potential Application: Small SEP Vehicle - ISS deploy to Lunar Orbit
Total mass < 100 kg





STMD Centennial Challenges

Cube Quest Challenge

$5.0M Allocated Prize Money

The objective of the Cube Quest Challenge is to design, build, and deliver flight-qualified, small satellites capable of advanced operations near and beyond the Moon that demonstrate innovations in small spacecraft propulsion and communications techniques.

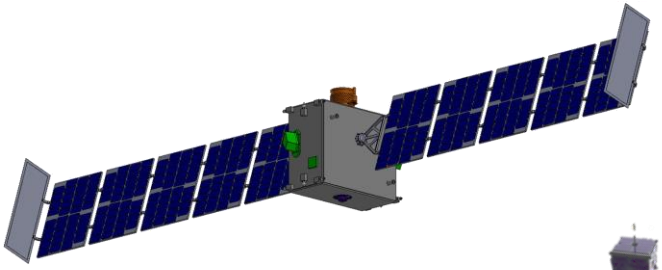
The top three contenders will be provided launch opportunities to deep space on the SLS EM-1 mission.

Prize competitors can also arrange their own rideshare launch.

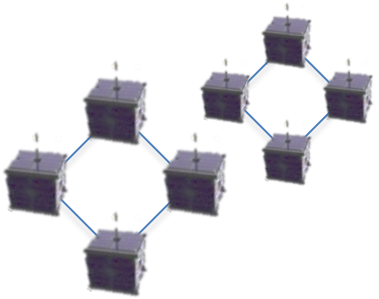
http://cms.nasa.gov/cubequestchallenge

Future Technology Interests

- **Small Solar Electric Propulsion**
  (Earth obit and beyond)

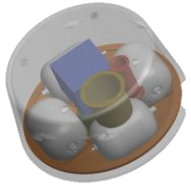


- **Science & Communications Constellations**
  (including advanced laser communication)



- **Inspector/Explorer Cubesats**
  (Earth obit and beyond)

- **Small Entry Vehicles and Testbeds**



- **Low-Cost Deorbit**

- **Nano-Launcher Capability**

NASA Science Solicitations Available to CubeSat Community

Science

SMD ROSES:

wide range of topics spanning SMD's four Science Divisions

Small Innovative Missions for Planetary Exploration (SIMPLEX):

missions using small spacecraft

SALMON-2 AO.

Earth Venture Instrument

Earth Venture Mission

missions of opportunity for cubesats

Technology

ESTO/InVEST: In-Flight Validation of Earth Science Technologies:

space validation of instruments

Heliophysics Technology and Instrument Development for Science:

space validation of instruments

Training

Hands-On Project Experience

Undergraduate Student Instrument Project

NASA Science Sponsored Small Spacecraft Solicitations

Solicitation Name	Award amount	Anticipated Selections/Year	Discipline
SMD/ROSES/ H-TIDeS/APRA	$1.5M - $5M	2-3	Science / Instrument Technology
SMD/ESTO InVEST	$1.5M	3	Earth Science Technology
SMD/Earth Venture-Instrument	$30M for Cubesat mission	Multiple Awards every 2-3 years	Earth Science
SMD/Earth Venture-Mission	$160M (incl. launch)	Multiple Awards every 2-3 years	Earth Science
SMD/Explorer MO	$60M	Multiple awards every 2-3 years	Astrophysics
SMD/HOPE-TO	$800K	1	Training
SMD/OE/USIP	$200K	Multiple awards every 2 years	Student Training

APD CubeSats

- Solicited via APRA and Explorer/MO, as ‘suborbital class’ projects. **Class refers to size of project,** even though CubeSats are in orbit.
- As with all suborbital programs, involvement of students and junior researchers is desired. Solicitations allow both technology development and science projects, and both have been proposed.
- Within APD, CubeSat science investigations are typically limited to the brightest few objects. Proposed science investigations include: very bright transients, nearby stars with planets, diffuse (bright) background studies.
- Proposals typically rely on CSLI to get to orbit, but we have had proposals requesting funding to cover commercial launch costs.

HPD CubeSats

- Solicited via H-TiDES and Explorer/MO, as ‘suborbital class’ projects.
- Solicitations allow both technology development and science projects, and both have been proposed.
- Within HPD, CubeSat science investigations are typically limited to the sensor or in situ measurements.

SIMPLEx (PSD) Solicitation

- The Small Innovative Missions for Planetary Exploration (SIMPLEx) Program solicitation supports the formulation and development of planetary science investigations that can be accomplished using a small spacecraft.
  - For SIMPLEx 2015, proposers are limited to 1U, 2U, 3U, and 6U CubeSats
- All proposed investigations must be responsive to the goals of the Planetary Science Division as described in the 2014 Science Mission Directorate Science Plan. Proposed investigations may target any body in the Solar System except for the Earth and Sun
- Maximum award amount is $5.6M. 22 proposal currently under review. The first SIMPLEx award is anticipated in FY15

SMD Cubesat Integration Panel (SCIP)

SMD created the SMD Cubesat Implementation Panel (SCIP) in FY2014

Program	Suborbital Research Program
Program Executive	David Pierce
Funding Resources	$5M
Supporting MD	HEOMD (CSLI) STMD (Tech)
Supporting Centers	KSC; GSFC/WFF
MD Providing Funding	As required
Applicable NPRs	NPR 7120.8
Smallsat Mission Selections/Funded	FY2014: 6 selections 6 funded
	FY2015: 2 selections 8 funded

SMD SCIP Goals

A. Make recommendations on the assigned SMD resources ($5M) toward sponsorship of highly ranked Smallsat science proposals from the SMD NRA (i.e., ROSES) science peer review selection process conducted by the respective sponsoring SMD Divisions.

B. Facilitate usage of Smallsats as an emerging SMD science platform and recommend appropriate Smallsat policy to facilitate community usage.

Sponsor	Mission	PI	Institution	Discipline	Access to Space
SMD	IceCube	Wu	GSFC	Earth	CSLI (2013)
SMD	TBEx	Tsunoda	SRI	Helio	CSLI (2015)
SMD	MinXSS	Woods	U Colo	Helio	Orb-4
SMD	CuSPP	Desai	SwRI	Helio	CSLI (2015)
SMD	SORTIE	Crowley	ASTRA	Helio	TBD
SMD	ELFIN	Angelopoulos	UCLA	Helio	CSLI (2014)
SMD	Astro-1	TBD	TBD	Astrophysics	TBD
SMD	SIMPLEX-1	TBD	TBD	Planetary	TBD EM-1

SMD/NRA CubeSat Proposal Statistics

Solicitation	Proposals Received	Missions Selected	Launched	Manifested	CubeSat Missions
Planetary	2	2	1	1	O/OREOS Nanosat INSPIRE
ESTO	3	3	3	0	M3Cove-2, GRIFEX, IPEX
ROSES-12	2	1	0	1	CERES
InVEST-12	23	5	0	5	MiRATA, RAVAN, LMPC , HARP ICECUBE
HOPE-12	2	1	1	0	CHARM/RACE
ROSES-13	26	5	0	5	TBeX, MinXSS, CuSPP, SORTIE, ELFIN
HOPE-13	2	0	0	0	
ROSES-14	17	0	0	0	
ROSES-15	In process (11)	In process	0	0	
SIMPLEx-15	In process (22)	In process	0	0	
InVEST-15	In process	In process	0	0	
USIP-15	In process	In process	0	0	
Total	>110	17	5	12	

TOTAL Selected 17

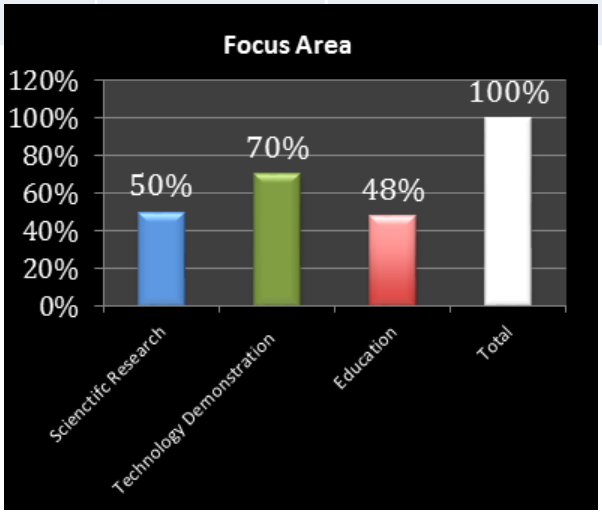
SMD CubeSats Summary

Mission	Institution	Sponsor	CSLI Manifest	LRD/ Launch Date
M3COVE-2	Michigan/JPL	ESD/ESTO		2013
IPEX	JPL	ESD/ESTO		2013
CHARM/RACE	JPL	SMD/HOPE; JPL		2014 (ORB-3)
GRIFEX	JPL/Michigan	ESD/ESTO		2015 (SMAP)
ESCAPE	GSFC	ESD/ESTO	2013	
MiRATA	MIT	ESTO/InVEST-12	2014	NET 2016
RAVAN	JHU/APL	ESTO/InVEST-12	2014	NET 2016
LMPC	Aerospace	ESTO/InVEST-12	2014	NET 2016
HARP	UMBC	ESTO/InVEST-12	2013	NET 2016
IceCube	GSFC	ESTO/InVEST-12	2013	NET 2016
CYGNSS (8)	Mich/SwRI	ESSP/EVS-1		2016
TEMPEST-D	CSU	ESSP/Evi-2	2015	
CeREs	GSFC/SwRI	HPD/LCAS	2014	2016

SMD CubeSats Summary

Mission	Institution	Sponsor	CSLI Manifest	LRD/ Launch Date
HeDI	GSFC	HPD	2011	
TBEx	Michigan	HPD/LCAS	DoD	2016
MinXSS	Colorado	HPD/LCAS	ISS	2015
CuSPP	SwRI	HPD/LCAS	2015	2016
SORTIE	Astraspace	HPD/LCAS	2015	2017
ELFIN	UCLA	HPD/LCAS	2014	2016
INSPIRE	JPL	PSD	2014	2016

SCIENCE MISSION DIRECTORATE	20
Earth Science Directorate (ESSP)	2
Earth Science Technology Office	9
Heliophysics Science Division	1
Low-Cost Access to Space (LCAS) Program	6
Planetary Science Division	1
Science Mission Directorate	1



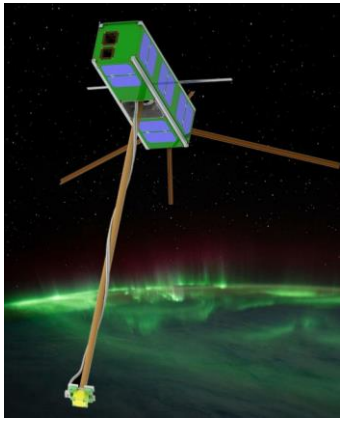
Highlighted Science Investigations

SMD is selecting cubesat investigations across its four science disciplines to enable scientific discovery, precursor spaceflight technologies, and to foster hands-on student flight research.

- ***GRIFEX (GEOCAPE ROIC In-Flight Experiment)*** – JPL/Michigan
  Earth Science Technology Office (ESTO) investigation supporting Atmospheric and Coastal Ocean Science to verify performance of fast imaging readout Integrated Circuit (ROIC) necessary to develop focal plane arrays (FPAs) with many pixels and high frame rates to support future Earth science missions. GRIFEX was launched as a secondary payload aboard the Soil Moisture Active Passive (SMAP) mission on January 31, 2015.

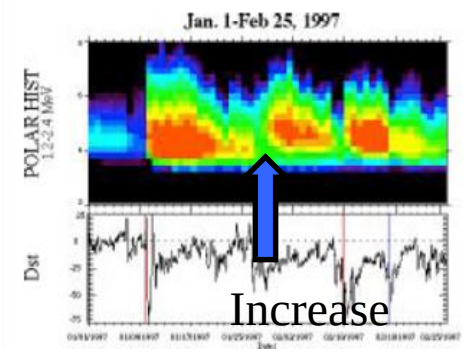
PI: David Rider, JPL

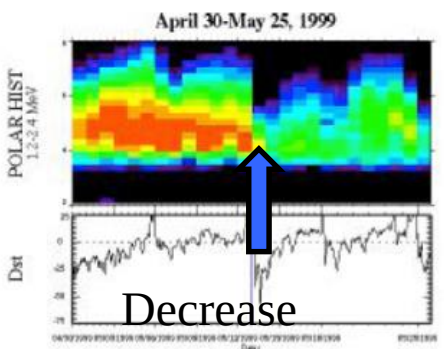
- ***ELFIN (Electron Losses and Fields Investigation)*** – UCLA
  Heliophysics Science Division (HPD) investigation to advance our understanding of Geospace Storms, and the dominant wave-loss mechanism of relativistic “killer” electrons from the radiation belts. ELFIN will measure, for the first time, the angle and energy distribution of precipitating electrons, and will compare the measured loss rates and electron properties during storms with theoretical models. ELFIN is approved by CSLI and will be manifested on a launch in 2016.

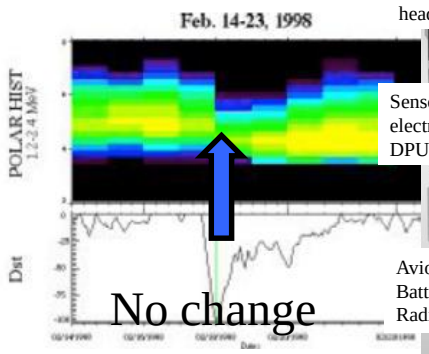


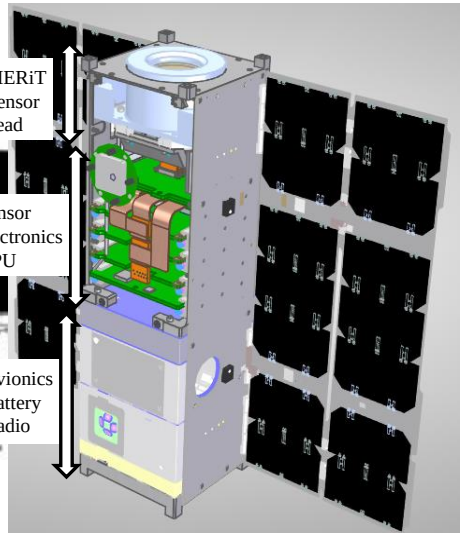
Highlighted Science Investigations

- ***CeREs*** – GSFC/SwRI ***Heliophysics Division (HPD)*** - Compact Radiation Belt Explorer. First fully-SMD funded CubeSat investigation to study Electron loss due to microbursts; Radiation belt electron dynamics; and solar electron energization and transport, and electron intensity after geomagnetic storms. CeREs was selected by CSLI and will be manifested on a launch in 2016.







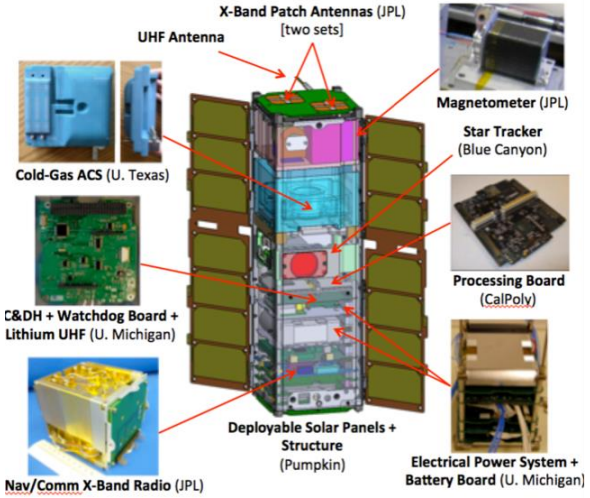


CuSPP: CubeSat mission to study Solar Particles over the Earth's Poles – SwRI. ***Heliophysics Science Division(HPD)*** - Suprathermal ion tails are ubiquitous throughout the heliosphere. Comprise material from many sources – highly variable in time and space. Current instruments are not optimized to measure suprathermal ions. ***Top priority for NASA's Heliophysics Division & notional mission Interstellar Mapping and Acceleration Probe in the 2012 Decadal Survey*** . CuSPP measures solar and interplanetary suprathermal ions that enter the Earth's polar regions via open field lines.

Highlighted Science Investigations

- ***IceCube/Earth-1*** – GSFC
  Earth Science Division (ESD) investigation demonstrate and validate a new 874-gigahertz submillimeter-wave receiver that could help advance scientists' understanding of ice clouds and their role in climate change. IceCube will lead to the development of an instrument capable of providing an accurate daily assessment of the global distribution of atmospheric ice. IceCube is approved by CSLI and will be manifested on a launch NET 2016.

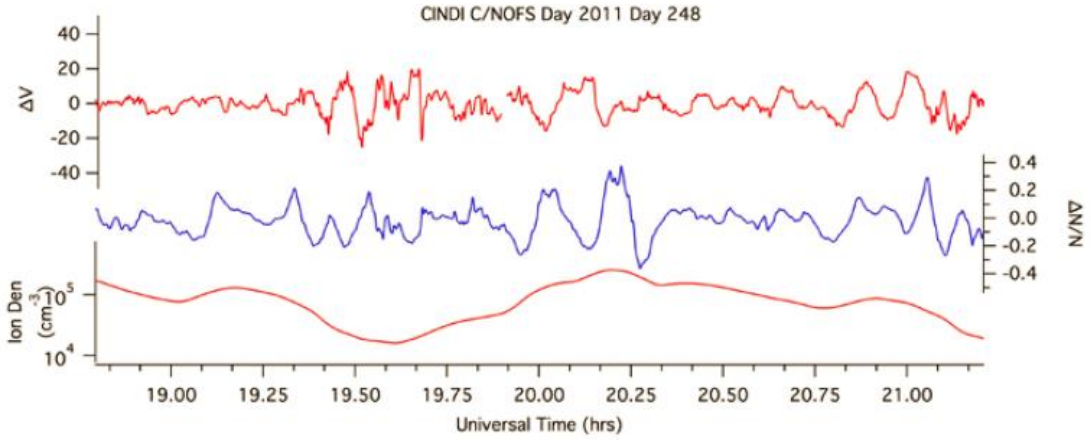
- ***INSPIRE: Interplanetary NanoSpacecraft Pathfinder In a Relevant Environment*** – JPL/CalPoly .
  Planetary Science Division(PSD) investigation to demonstrate the revolutionary capability of deep space cubesats by placing a nanospacecraft in Earth-escape orbit. The primary objectives of INSPIRE is to demonstrate that cubesats can operate, communicate, and be navigated far from Earth. Spacecraft components, such as the Iris X-band radio, and the robust watchdog system will provide the basis for future high-capability, lower-cost-risk missions beyond Earth. INSPIRE is approved by CSLI and will be manifested on an upcoming launch in NET 2016 timeframe.



Highlighted Science Investigations

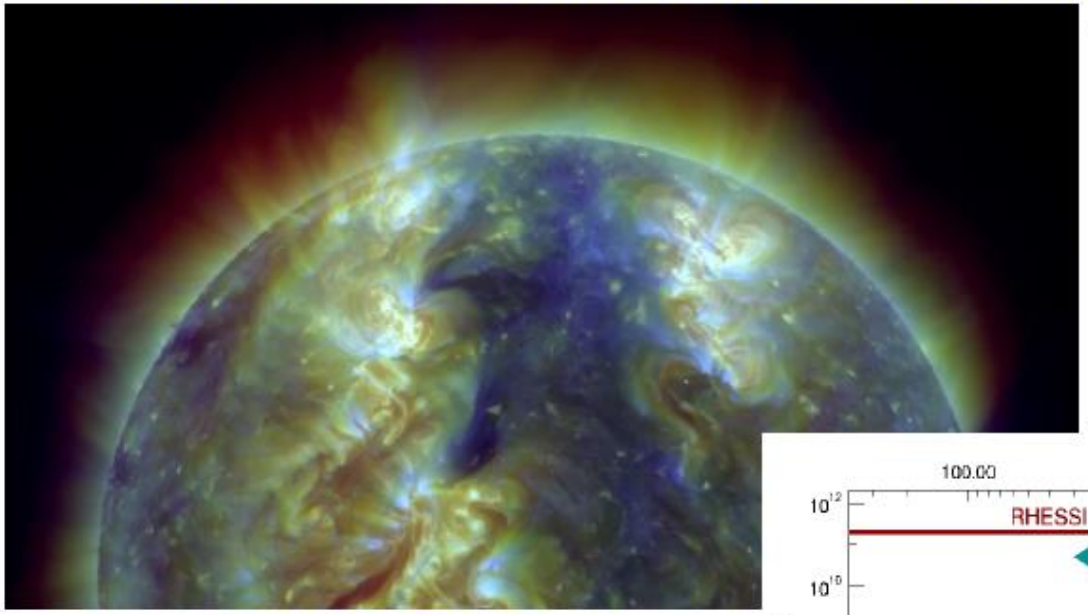
- ***TBeX***– Michigan, ***Heliophysics Division (HPD)*** – Tandem Beacon-Explorer will address a scientific challenge in 2012 NRC Decadal Survey: Understand how forcing from lower atmosphere acts through plasma-neutral coupling processes to give rise to local, regional, and global-scale structures and dynamics in the atmosphere-ionosphere-magnetosphere system. TBEx will monitor (1) response of bottomside *F* layer to wavelike disturbances from below, with sampling intervals less than orbital period, and (2) development of equatorial plasma structure, including 'equatorial plasma bubbles' (EPBs). TBEx mission is expected to provide a better understanding of the physics that controls the day-to-day variability in development of EPBs (space weather)

- **SORTIE – ASTRA, SDL *Heliophysics Division (HPD)*** – Scintillation Observations and Response of The Ionosphere to Electrodynamics will Measure phase delay between the velocity components parallel and perpendicular to the magnetic field and the plasma density perturbation to discover the sources of wave-like plasma perturbations in the F-Region ionosphere; to determine the relative role of dynamo action and more direct mechanical forcing in the formation of wave-like plasma pertrubations.



Highlighted Science Investigations

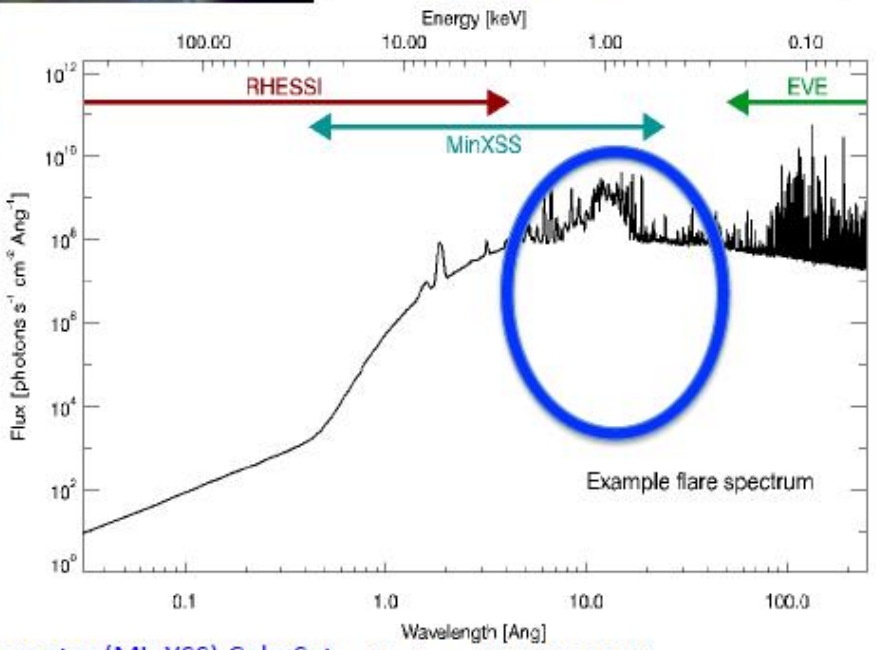
MinXSS Science Motivation #1 – Flares



To better understand the energy distribution of solar flare soft X-ray (SXR) emissions:

- Flare energetics
- Nanoflare heating of the corona

- Largest flare enhancements are expected near 10-20 Å (1-2 nm) from solar models, but there are very few SXR spectra measured during flare events [Rodgers *et al.* 2006].
- Rocket X123 measurements suggest nanoflare heating in the more active Sun measurement in 2013 than in the quiet Sun measurement in 2012 [Caspi et al., 2015].

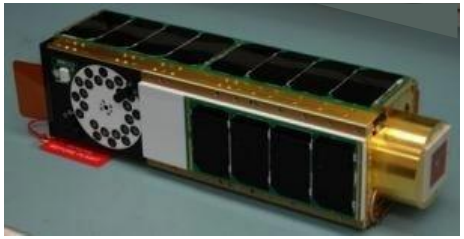


Movie credit: NASA SDO AIA

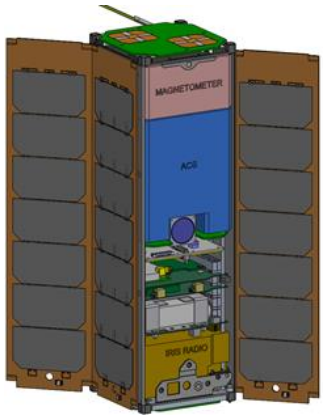
Highlighted Science Investigations

Planetary (PSD) CubeSat Missions

- Previous planetary science CubeSats, not developed under SIMPLEx:
  - O/OREOS Nanosat – Organism/Organic Exposure to Orbital Stresses
    - Developed in the SMD Astrobiology Small Payloads Program. Launched Nov 19, 2010
    - Full mission success resulting in 4 refereed papers published
  - INSPIRE – Interplanetary NanoSpacecraft Pathfinder in a Relevant Environment
    - Selected for launch by NASA's CubeSat Launch Initiative Program



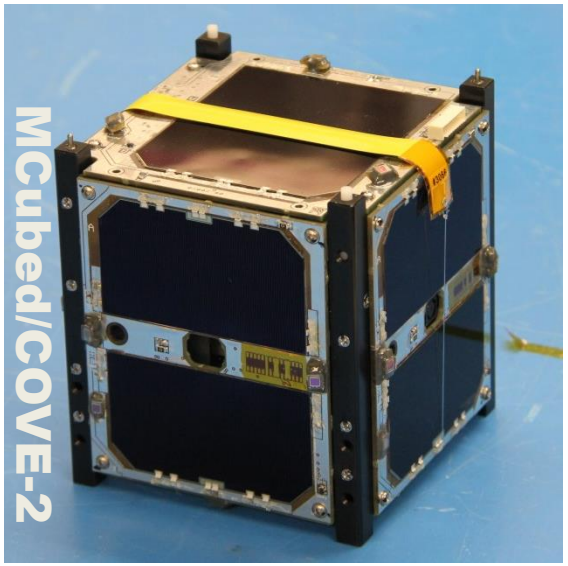
O/OREOS Nanosat



INSPIRE

Highlighted (ESTO) Technology Investigations

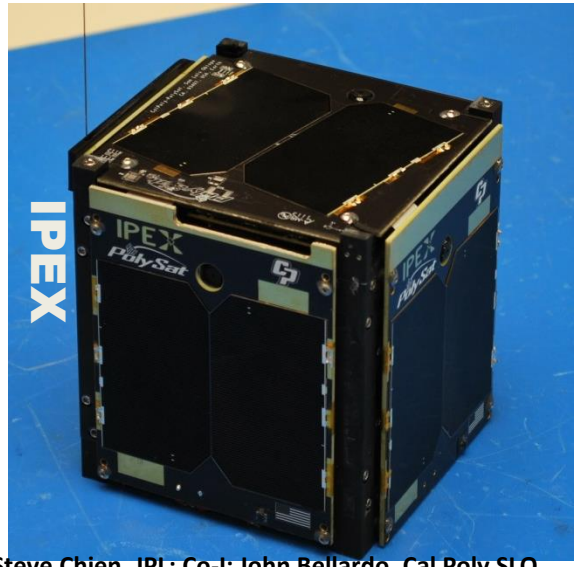
Two CubeSats launched from Vandenberg Air Force Base (2013)as part of NASA's CubeSat Launch Initiative on the NROL-39 Atlas V.



The Michigan Multipurpose Minisatellite (MCubed-2), built by the University of Michigan, carried the JPL-developed CubeSAT On-Board Processing Validation Experiment (COVE). COVE validated the Multiangle Spectropolarimeric Imager (MSPI) algorithm using a new radiation-hard-by-design FPGA. This technology validation mission will advance the TRL for a spaceborne MSPI instrument targeted for the ACE mission concept. MSPI is a high-data rate instrument designed to study cloud and aerosol science that will require on-board processing to reduce the data downlink requirements by two orders of magnitude.

PI: Paula Pingree, JPL; Co-I: James Cutler, UM

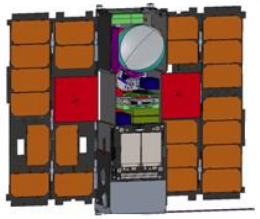
The Intelligent Payload Experiment (IPEX), built by Cal Poly San Luis Obispo and JPL, flew key aspects of the Intelligent Payload Module (IPM) technology targeted for the HyspIRI mission concept. The IPM enables near real-time autonomous product selection and generation providing a 20x reduction in data volume for high data rate thermal infrared imaging and visible to near-infrared spectroscopy instruments. IPEX's objective was to advance the technology readiness level of the IPM capability.



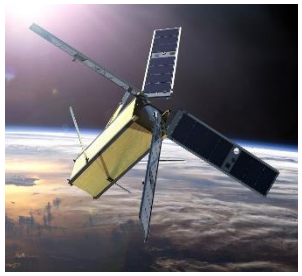
PI: Steve Chien, JPL; Co-I: John Bellardo, Cal Poly SLO

Highlighted (ESTO/InVEST) Technology Investigations

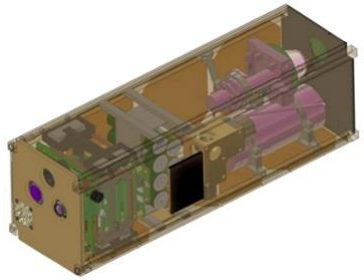
The need to space-validate new technologies is critical to reduce risk for future Earth science measurements. The In-Space Validation of Earth Science Technologies (InVEST) program is intended to fill the gap. The first InVEST solicitation sought small instruments and subsystems that advance technology to enable relevant measurements and targeted the CubeSat platform.



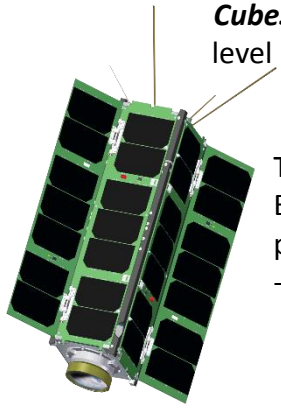
The ***Microwave Radiometer Technology Acceleration (MiRaTA) Cubesat*** will validate multiple subsystem technologies and demonstrate new miniature microwave radiometers operating near 52-58, 175-191, and 206-208 GHz that could dramatically enhance the capabilities of future temperature and humidity measurements. - K. Cahoy, MIT; **Launch NET 2016**



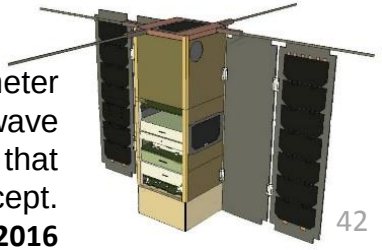
The ***Radiometer Assessment Using Vertically Aligned Nanotubes (RAVAN)*** project will demonstrate a bolometer radiometer that is compact, low cost, and absolutely accurate to NIST traceable standards. RAVAN could lead to affordable CubeSat constellations that, in sufficient numbers, might measure Earth's radiative diurnal cycle and absolute energy imbalance to climate accuracies (globally at 0.3 W/m2) for the first time. - W. Swartz, JHU/APL; **Launch NET 2016**



The objective of the ***Cubesat Flight Demonstration of a Photon Counting Infrared Detector (LMPC CubeSat)*** is to demonstrate in space, a new detector with high quantum efficiency and single photon level response at several important remote sensing wavelength detection bands from 1 to 2 microns. - R. Fields, Aerospace Corporation; **Launch NET 2016**



The ***HyperAngular Rainbow Polarimeter HARP-CubeSat*** will validate a technology required by the Aerosol-Cloud-Ecosystem (ACE) mission concept and prove the capabilities of a highly-accurate, wide-FOV, hyperangle, imaging polarimeter for characterizing aerosol and cloud properties.
- J. V. Martins, UMBC; **Launch NET 2016**



IceCube is a three unit (3U) CubeSat under development to validate a 874-GHz radiometer receiver for future use in ice cloud measurement missions. This submillimeter wave radiometer technology could directly benefit an ice cloud imaging radiometer such as that called for by the Aerosol-Cloud-Ecosystem (ACE) mission concept.
- D. Wu, NASA Goddard Space Flight Center; **Launch NET 2016**

Highlighted (ESTO/InVEST) Technology Investigations

IceCube to Validate 874 GHz Radiometer

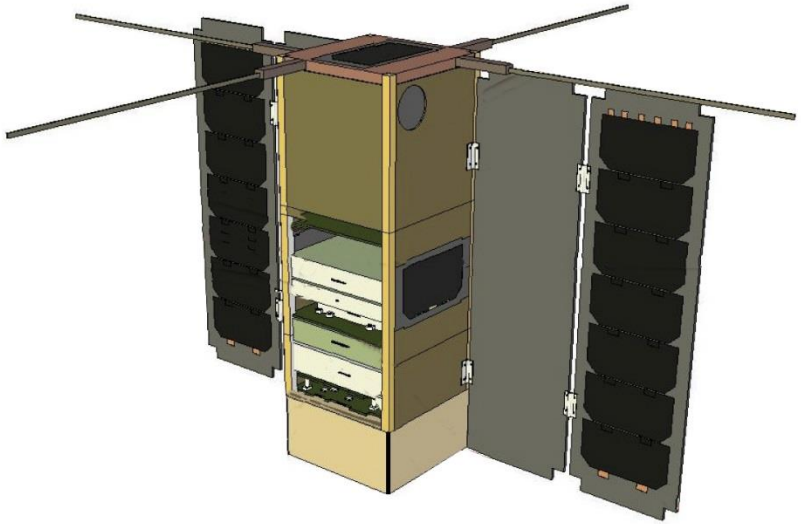
IceCube – is a three unit (3U) CubeSat under development to space validate a 874-GHz radiometer receiver for future use in ice cloud measurement missions. The GSFC award is a partnership with Virginia Diodes, Inc.

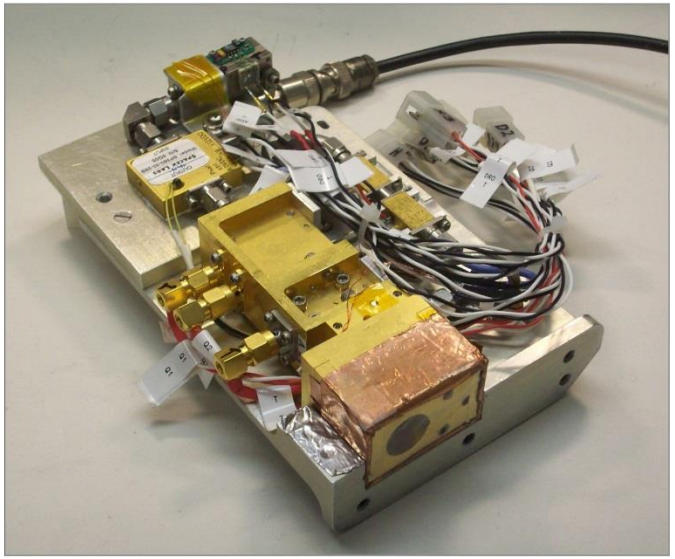
Once validated, this sub-millimeter wave radiometer technology could directly benefit an ice cloud imaging radiometer such as that called for by the Aerosol-Cloud-Ecosystem (ACE) mission concept. Improved measurements of ice clouds and ice water path are critical to global circulation models and to our understanding of their role in climate change.

Selected as one of six projects recommended by the Science CubeSat Integration Panel (SCIP) in mid-May 2014, the project has also been selected by the NASA CubeSat Launch Initiative and is targeted to be ready for launch within two years.

The IceCube team is aiming for a 28+ day mission that includes extended observations of periodic deep space and near nadir Earth scenes.

PI: D. Wu, GSFC





Top: Conceptual drawing of the IceCube 3U CubeSat.
Bottom: The 874-GHz receiver
(Image Credit: D. Wu)

Challenges: Spectrum

Given short life-cycles, development teams with limited flight experience, and mixed government/non-government teams, some small sats have encountered challenges in regards to spectrum

(a) For example, the typical one or more year spectrum coordination process and detailed technical rules that permit shared use of the spectrum can be a challenge for small sats that typically have a fast development life-cycle and limited experience

(b) Many frequency bands (> 25) have been used to support small sats (see backup chart)

From a spectrum requirements and frequency coordination perspective, small satellites (e.g., nanosatellites, etc.) can not be defined as a distinct satellite class . . . An emitter is an emitter no matter what size the platform or spacecraft (per ITU studies)
- Existing spectrum regulations apply to ALL spacecraft. . .

(a) Authorization/licensing required;

(b) Must follow regulations including technical parameters (e.g., power flux density limits);

(c) Must follow satellite notification and coordination processes.

NASA/Spectrum is educating the NASA community and developing spectrum guidance for the NASA small satellite community (draft in review)

Challenges: Communication & Navigation Support

Many different communication & navigation support approaches have been used:

(a) Many small satellite projects have procured their own ground stations (e.g. Ultra-High Frequency (UHF) Yagi antenna, or a small 2m dish);

(b) Commercial ground networks (e.g., KSAT) are increasingly deploying systems to support small satellites;

(c) A few small satellite systems, solicit support from amateur operators around the world ("crowd sourcing") to collect and send data packets back to a mission control center (e.g., University of Michigan);

(d) Both Iridium and Globalstar mobile satellite systems have supported small sats;

(e) No one or set of standards has emerged as the obvious choice for small satellites.

Other Challenges

- Approvals for propulsion systems, radioactive materials, or explosive devices for deep space CubeSat missions
- Availability of award funding for CubeSat missions selected under CSLI

Exciting trend for CubeSats over next 5 years

- ***The First Planetary CubeSat Mission*** will launch (JPL/MarCO in 2016) and the moon (Lunar IceCube)
- Number of SmallSats will continue to grow and both government and commercial companies will develop and launch large constellations of SmallSats. CubeSat components will become more robust, reliable, smaller, lighter, faster, cheaper, etc.
- (SMD) expects the number of proposals to remain the same or increase, and the quality to increase as the community puts more effort into CubeSat proposals. Will select ~ 2-3 Cubesat missions per year over the next 5 years. Cubesats will become a stable component platform of the SMD Science Program, supporting all four Science Divisions. SIMPLEx-1 selection in FY15, with EM-1 launch of SIMPLEx-1 anticipated in 2018. Selection of SIMPLEx-2 anticipated in FY17.
- (STMD) will make great progress in fields of Communications, Propulsion, Power, and Attitude Control through STMD Technology Partnerships
- (HEOMD/CSLI) will continue to find new ways to find launch opportunities and may be able to relax some launch/operational restrictions
- (HEOMD/SCaN) is educating the NASA community and developing spectrum guidance for the NASA small satellite community. Space Communication and Navigation Program has initiated activities to support the small sat community including assessing long-term capabilities and potential collaborative activities

Studies Guiding the Path Forward

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

(a) Investigate current paradigm shifts in the miniaturization of science instruments and disruptive small satellite platform technologies;

(b) Determine the potential for novel approaches that could break the cycle of "larger but fewer" expensive missions;

(c) Identify key SMD science measurement requirements that could be satisfied through such paradigms;

(d) Identify technology gaps to address through solicitations to remove barriers to alternative paths.

SMD-Directed NRC Study of Achieving Science Goals with Cubesats

(a) Summaries status, capability, availability, and accomplishments of selected existing cubesat programs in government, academic, and industrial sectors;

(b) Recommend potential near-term investments to improve capabilities with high impact on science and technology return — to increase the value of cubesats to science and to enable wider use of cubesats;

(c) Identify priority near-term science goals such as providing continuity of key measurements to mitigate potential gaps in measurements that can be accomplished with current cubesat capabilities.

Summary

NASA manages its small spacecraft activities to enable scientific discovery, innovative space technologies, and hands-on flight research.

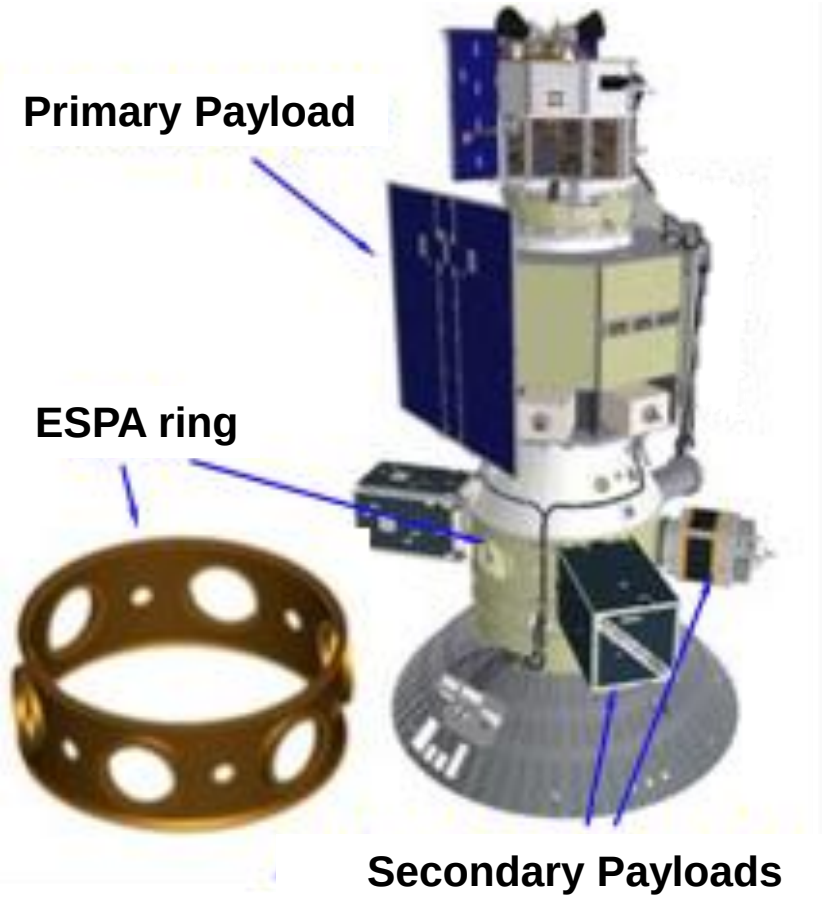
- Small spacecraft provide an important proving ground for advancing scientific and technology research while lowering the risk for subsequent flight projects.
- Small spacecraft can carry out significant science investigations and serve as a technology test bed in the relevant environment at a fraction of the cost of larger orbital flights.
- NASA is fostering a stable customer base for an emerging commercial small spacecraft market by sponsoring of industry and university research and providing reliable access-to-space.
- Small spacecraft efforts are cultivating the next generation of researchers and technologists.

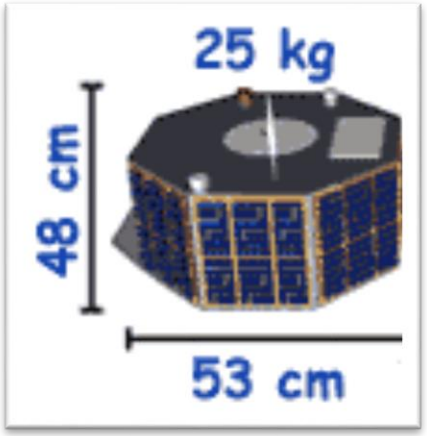
Backup Slides

Background: Cubesats and Smallsats

What is a small spacecraft or smallsat?

- a spacecraft that is small enough to be launched as a secondary payload, typically 180 kg or less





ST5 spacecraft
Launched in 2006

Small spacecraft are not limited to Earth orbiting satellites but can include small interplanetary spacecraft, landers, and entry vehicles

Background: Cubesats and Smallsats

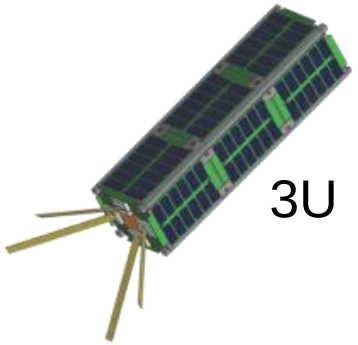
What is a Cubesat?

- A special category of small spacecraft of a standard size
  1 cubesat unit (1U) = 10 x 10 x 10 cm (a 4-inch cube)
  Cubesats are built in 1U, 1.5U, 2U, 3U, 6U and larger sizes

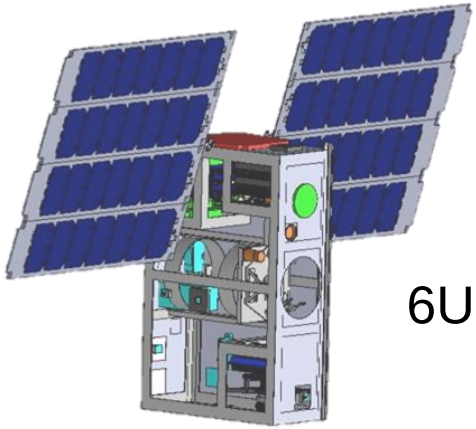
1U cubesat and deployer

1U

1.5U



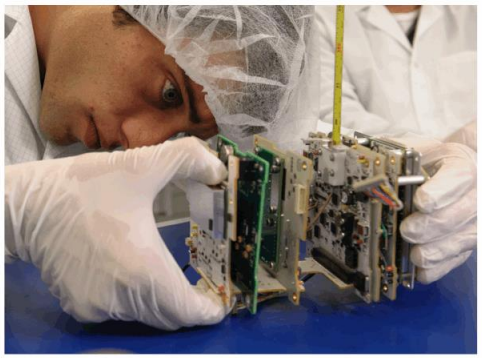
3U



6U

The key features that make cubesats affordable are standard size and form and containerization for launch.

Background: Cubesats and Smallsats



Features that make smallsats, and especially cubesats, different from conventional spacecraft:

- Lower cost
- Rapid development
- Higher risk tolerance
- Standardized launch interfaces (ESPA ring, P-POD)
- “Build, test, and fly” versus extensive analysis
- Greater use of off-the-shelf components
- Lower barrier-to-entry for space missions (university and small businesses, etc.)
- Possibility for unique applications (i.e., large constellations)

CSLI Benefits

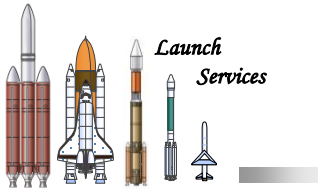
Benefit to Educational Organizations and Non-profits:

- Enables students, teachers and faculty to obtain hands-on flight hardware development experience
- Advances the development of technologies
- Provides mechanism to conduct scientific research in the space environment
- Provides meaningful aerospace and Science, Technology, Engineering and Mathematics (STEM) educational experience

Benefit to NASA:

- Promotes and develops innovative public-private partnerships
- Provides a mechanism for low-cost technology development and scientific research
- Enables the acceleration of flight-qualified technology assisting NASA in raising the Technology Readiness Levels (TRLs)
- Strengthens NASA and the Nation's future STEM workforce

CSLI Implementation Partnerships



Partnerships with other US Government Agencies/Departments

- NASA has established inter-agency agreements with USAF and NRO for CubeSat integration onto non-NASA launches
- NASA assists non-government CubeSat developers in seeking FAA, FCC and NOAA licenses (as necessary)

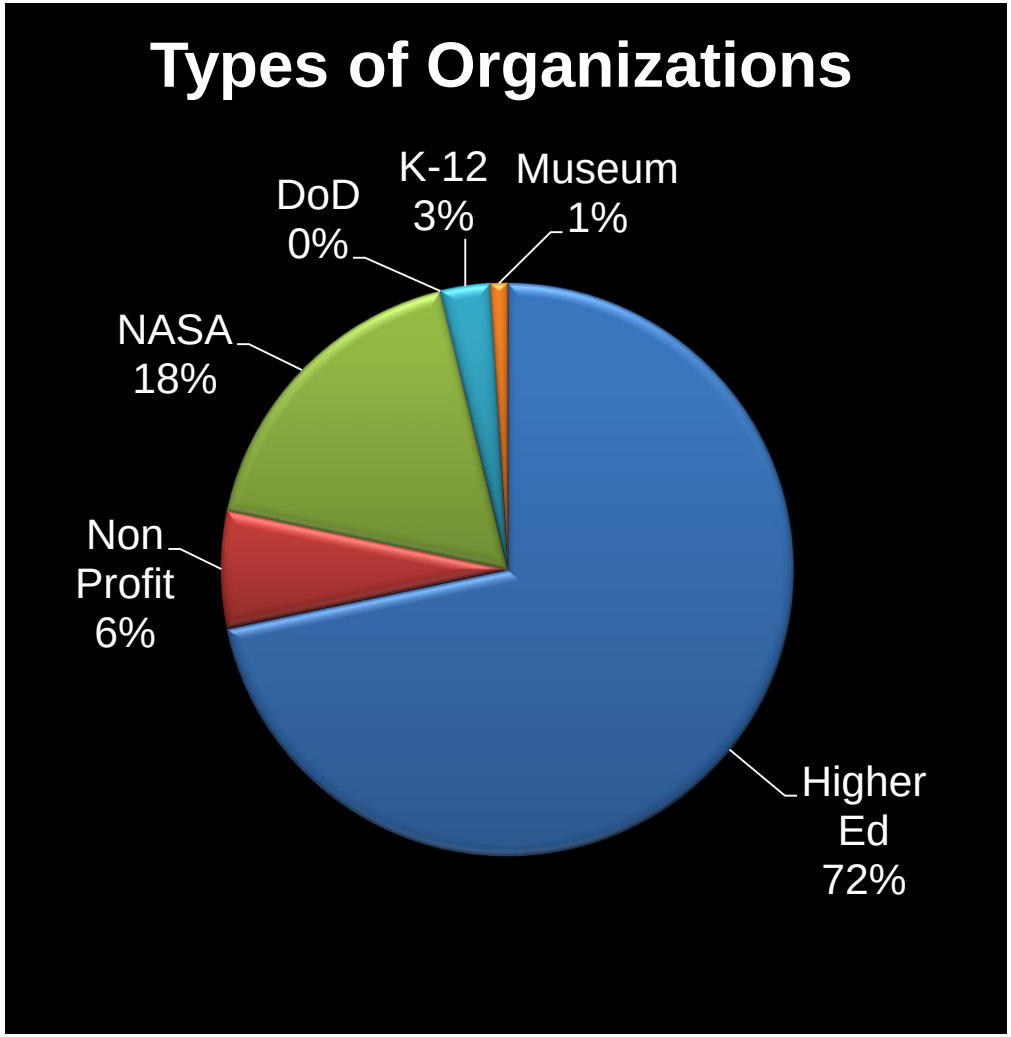
Partnerships with commercial entities

- NASA has established CubeSat Dispenser Hardware and Integration Services (CSDHISC) IDIQ contract to provide integration hardware and perform integration activities

Partnerships with commercial entities

- Public-Private Partnerships – Cooperative Research and Development Agreements with U.S. universities, Non-profits and NASA Centers to provide low-cost technology development and scientific research.
  - 106 projects involving 44 universities, five Non-profits and five NASA Centers

CSLI CubeSat Organizations



- Eligible Organizations include: Educational and Non-profits, NASA Centers
- Majority of proposing organizations are universities
- 60 Unique Organizations Selected
- 48% of the universities utilize Space Grant and Experimental Program to Stimulate Competitive Research (EPSCoR) Funding
- 2014 we launched TJ^{3}Sat, the first CubeSat built by and launched for a high school
- 2015 we will launch STEMSat, the first CubeSat built by and launched for a primary school

Recent Launches

ELaNa V

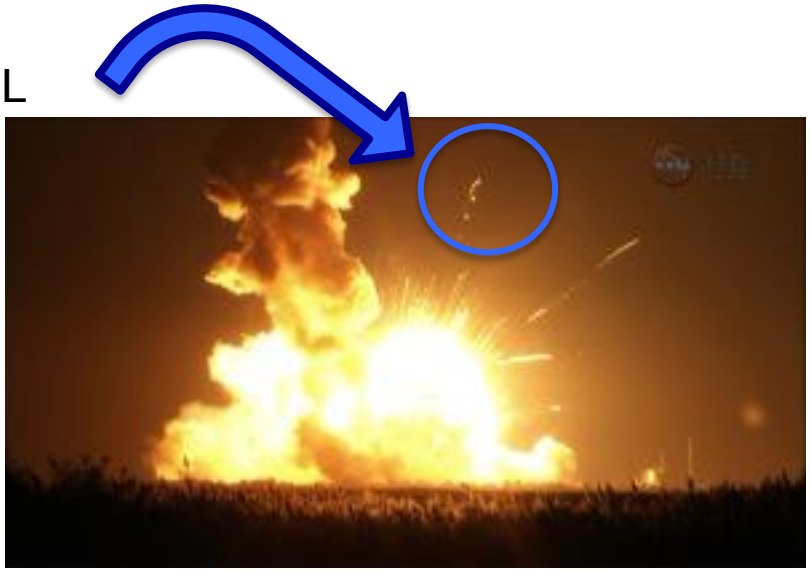
- All-Star/THEIA Colorado
- PhoneSat 2.5 AMES
- TSAT –TESTSat-Lite Taylor University
- KickSat: Cornell University
- SporeSat AMES

ELaNa X

- FIREBIRD-2 Montana State University
- GRIFEX University of Michigan
- ExoCube Cal Poly

ELaNa VIII

- RACE (CHARM) JPL



Manifested Missions

ELaNa X – August 2015 – Atlas V

- AMSAT Fox-1 Radio Amateur Satellite Corporation
- BisonSat Salish Kootenai College
- ARC University of Alaska – Fairbanks
- LMRST-Sat JPL

ELaNa VI – October 2015 – Super Strypi

- Argus - Saint Louis University
- PrintSat Montana State University

ELaNa IX – Nov 2015 – H2B/Atlas V

- MinXSS(HiLite) Colorado, Boulder
- STMSat-1 St. Thomas More Cathedral School

ELaNa XIII – December 2015 – Falcon 9

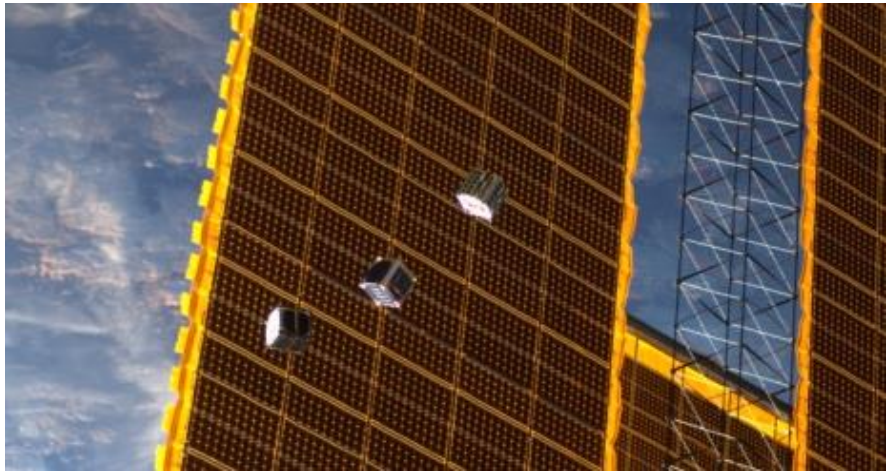
- ISARA - JPL
- E. Coli AntiMicrobialSat - ARC

Cubesat Deployments from ISS

Cubesats are delivered to ISS as pressurized cargo and later deployed into orbit using JAXA or commercial Nanoracks deployers

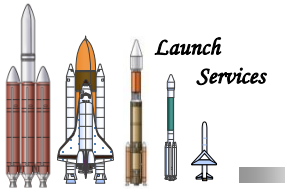
- agreement with Nanoracks allows 3U for NASA out of each 48U

Nodes will be STMD's first ISS deployed cubesat in November 2015



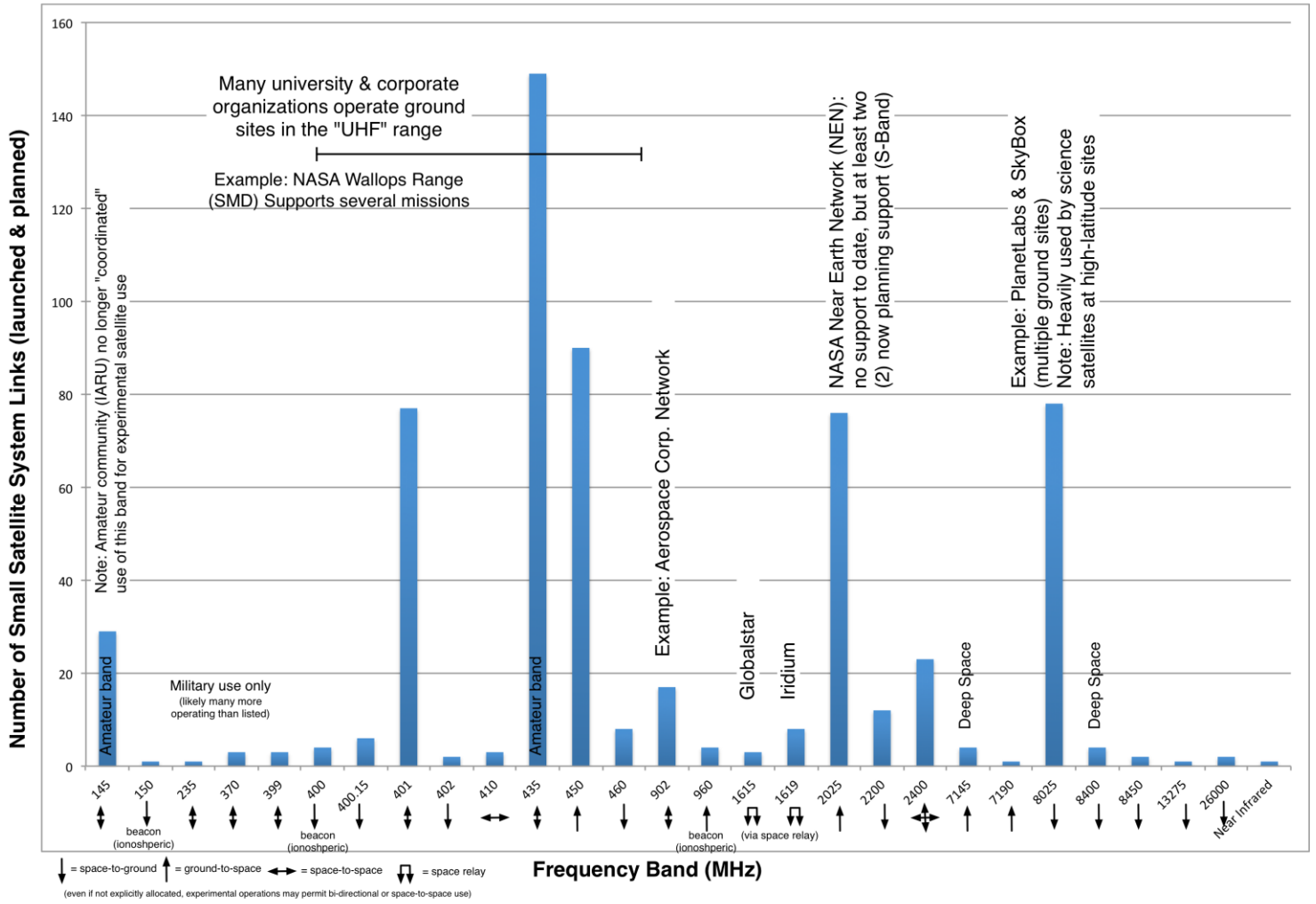
2009–2015 CubeSat

106 Selections – 60 Organizations – 30 States & DC

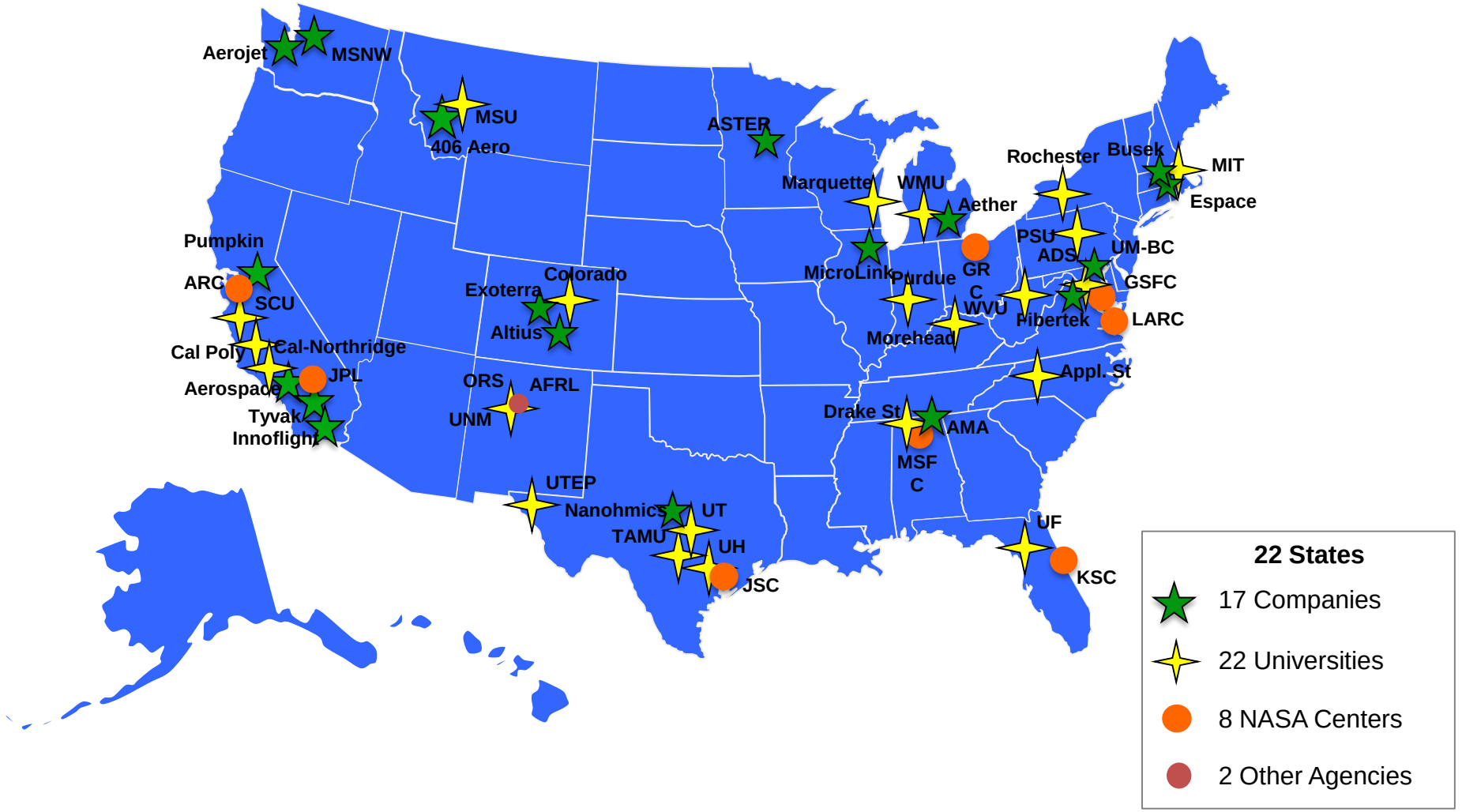


Challenges: Spectrum – Frequency Bands

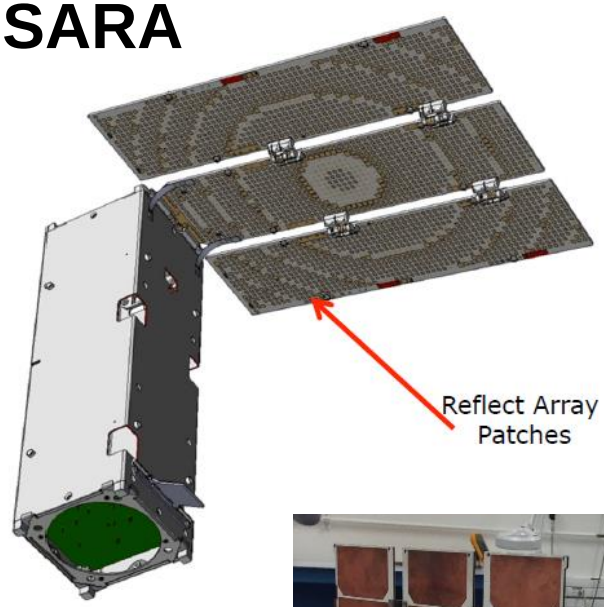
Based on partial insight into mission designs, at least 25 different frequency bands have been or are planned to be used by small satellites for communications . . . Not all are appropriate for sustained operations

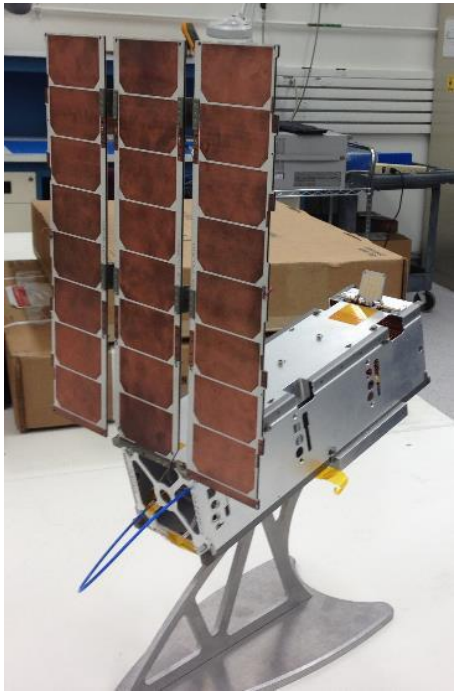


STMD/Small Spacecraft Technology
Nationwide Participants and Partners



Integrated Solar Array and Reflectarray Antenna ISARA





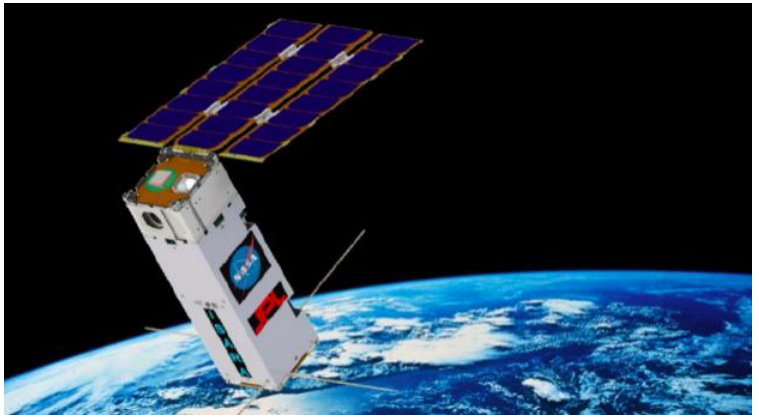
JPL, Aerospace Corporation, Pumpkin Inc.

Increased Ka-band communication and potential radar remote sensing.

Launch – December 2015
LCC: $5.5M FY13-15

Technology being used for MARCO cubesat radio relay on 2016 Mars Insight mission.

Technology being studied for RainCube Earth Science mission.

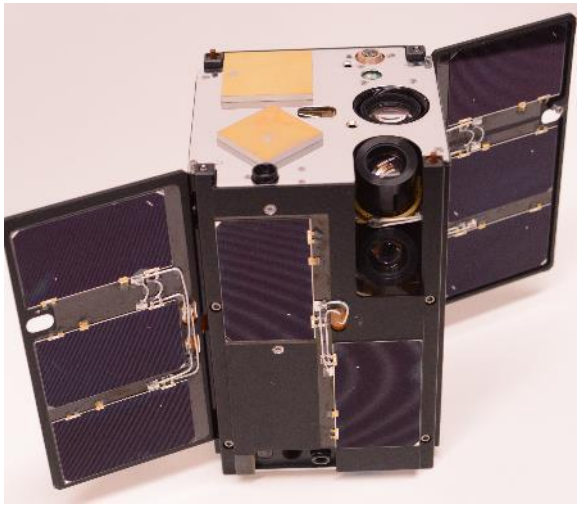


Optical Communications and Sensor Demonstration OCSD

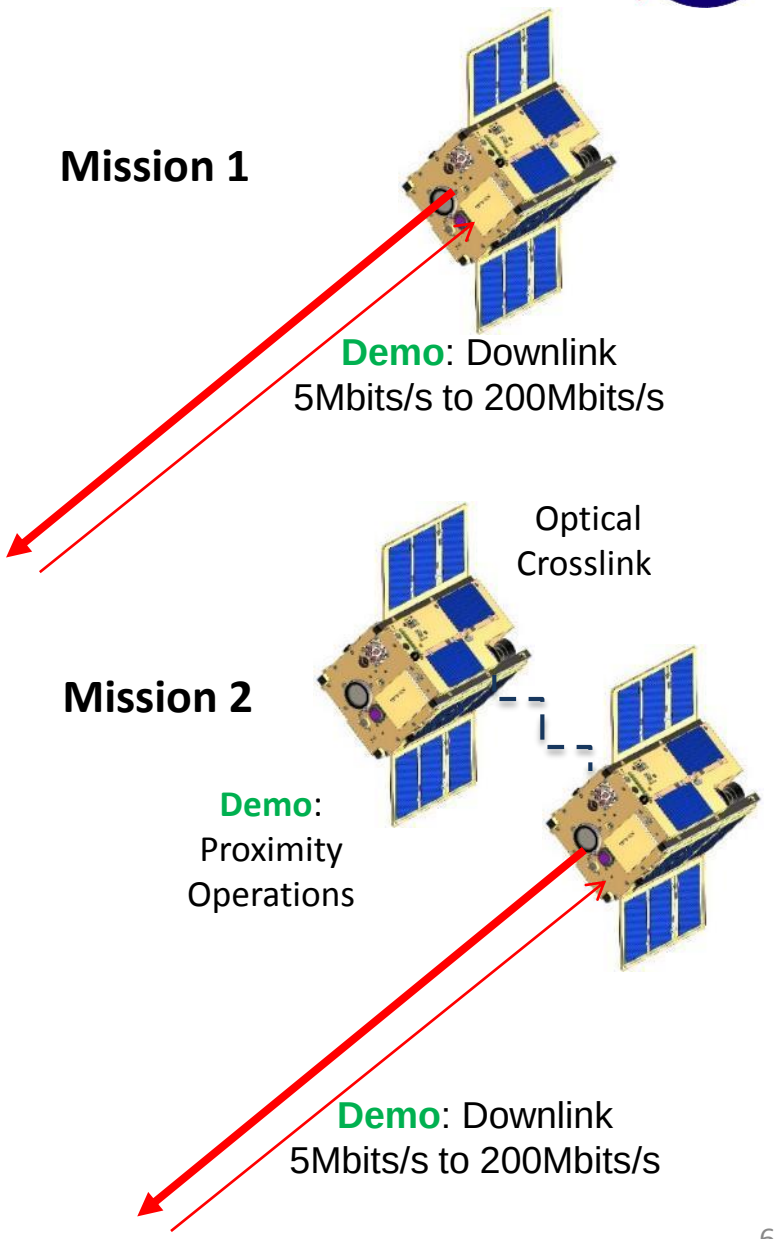
Aerospace Corporation

Space to ground and possible crosslink laser communications with 1.5U cubesats plus proximity operations, laser ranging and tracking, and propulsion.

Launches – August and December 2015
LCC: $3.5M FY13-15



First flight unit

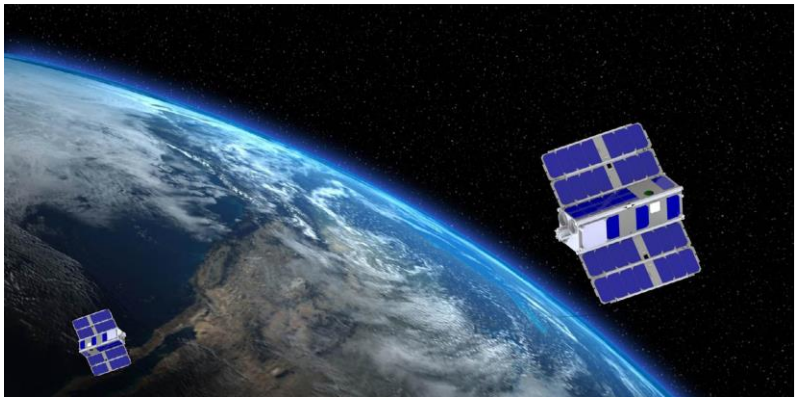


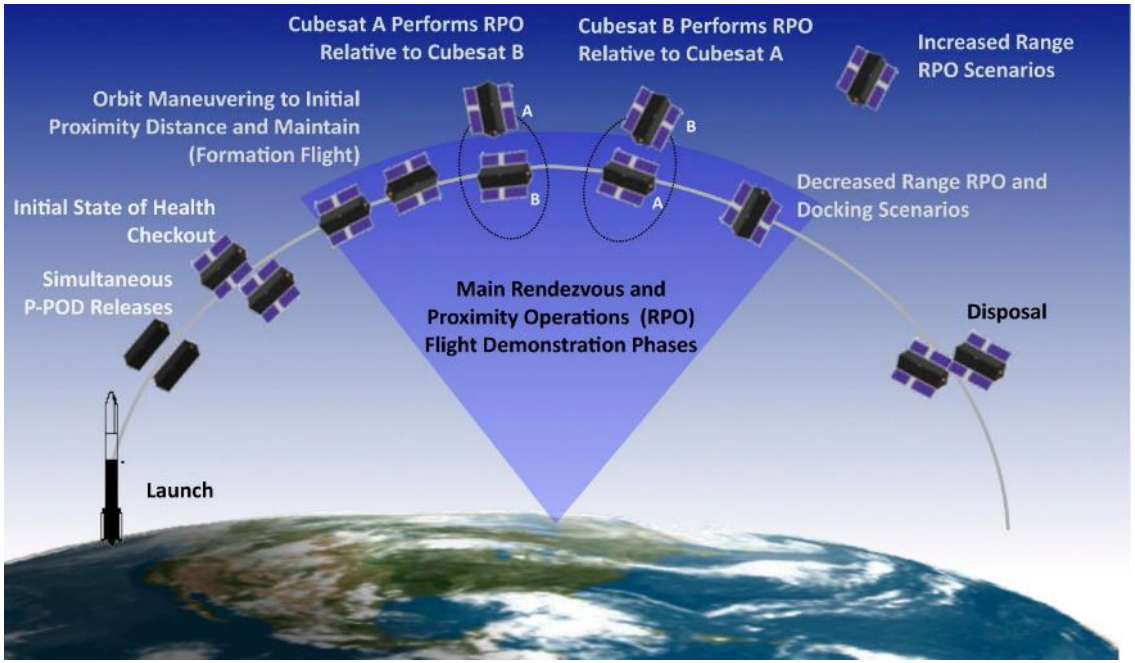
Cubesat Proximity Operations Demonstration CPOD

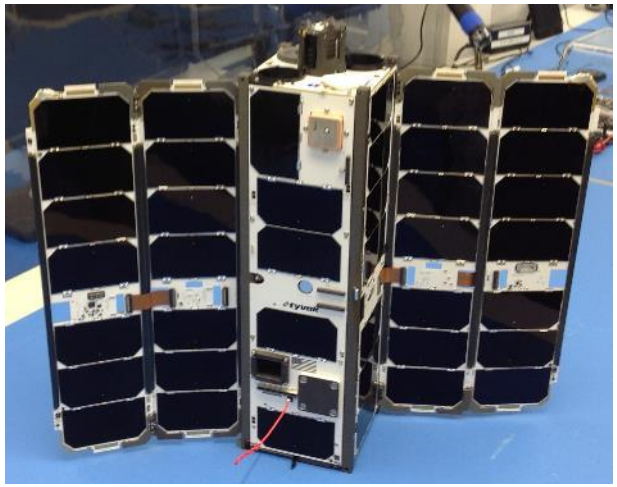
Tyvak LLC

Formation flight, proximity operations and autonomous rendezvous and docking with two 3U cubesats.

Launch – December 2015
LCC: $13.5M FY13-15







Engineering Development Unit

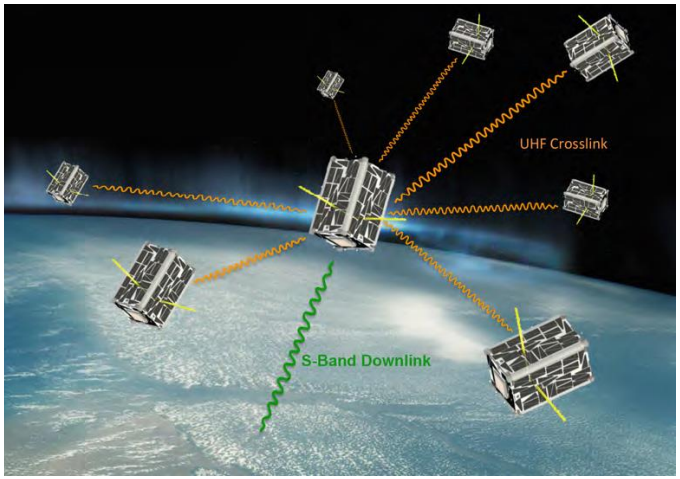
Edison Demonstration of Smallsat Networks (EDSN) And Nodes

NASA Ames, Montana State U and Santa Clara U

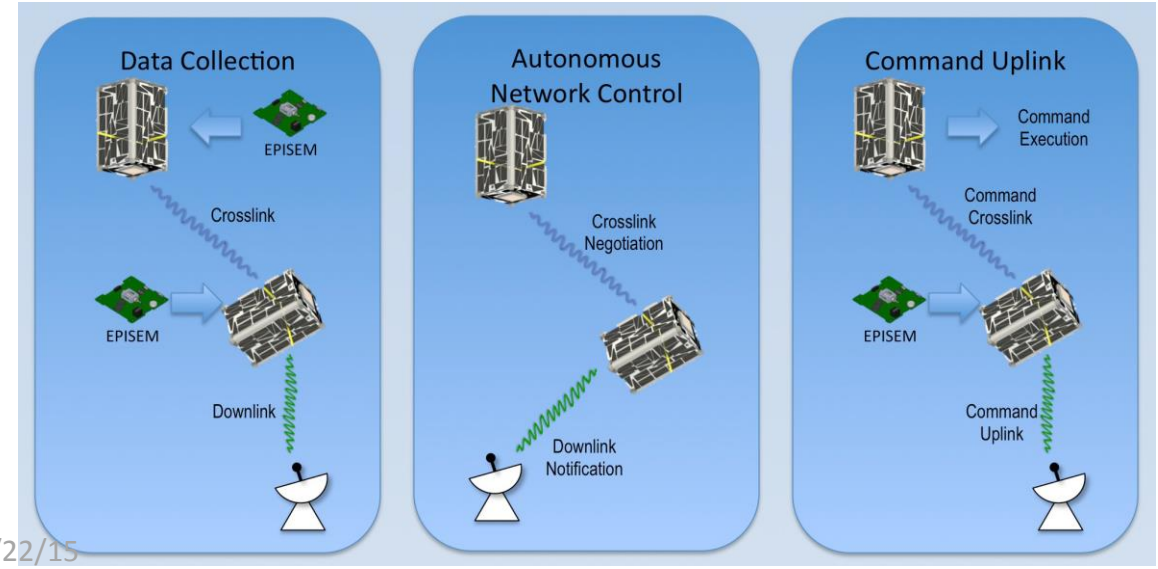
Demonstration of autonomous network communications with multiple low-cost satellites based on smartphone processors (Phonesat heritage) EDSN: 8 cubesats, Nodes: 2 cubesats

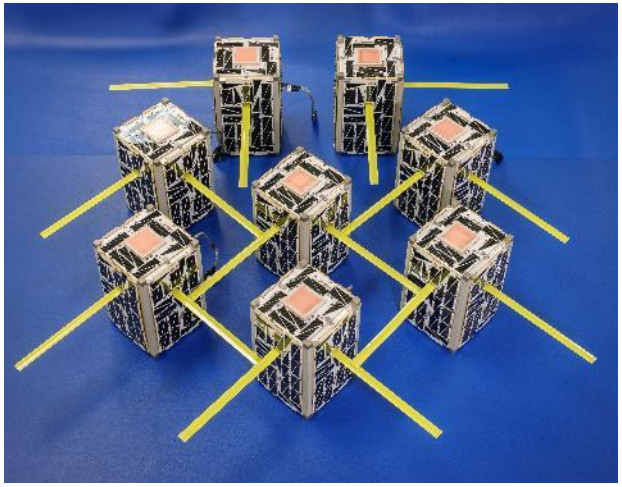
EDSN Launch – October 2015
Nodes Launch – November 2015 (ISS)
LCC: $16M FY12-15

EDSN Swarm



Nodes Operations



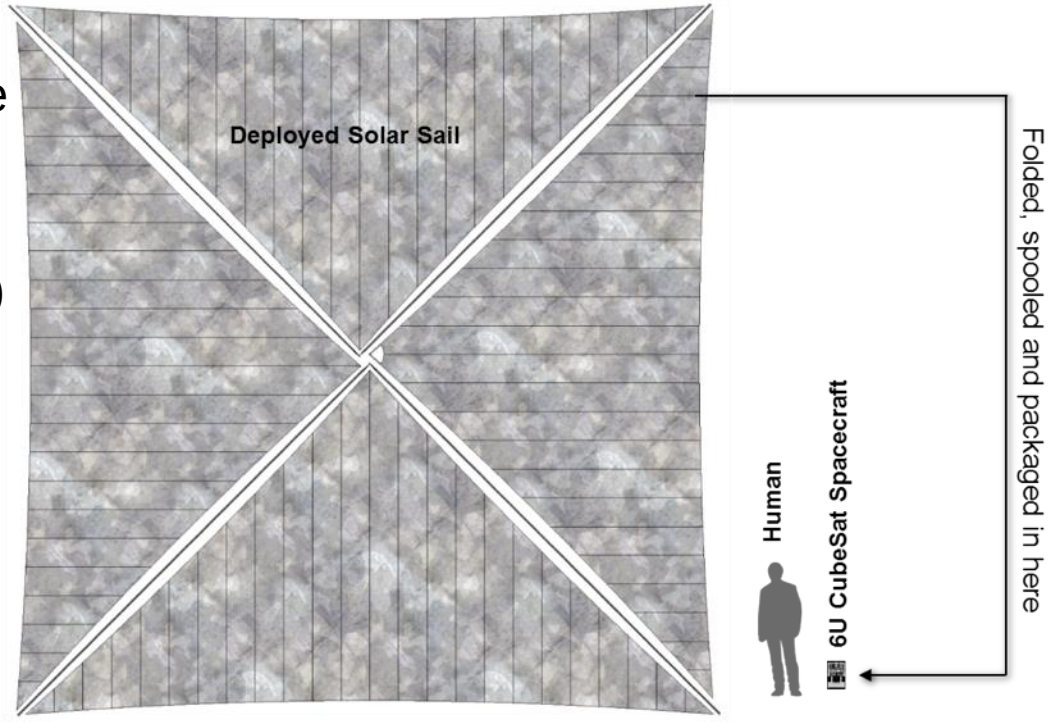


Flight Units

Solar Sail: Common System For Both Missions and The Future

- Commonality of sail design for NEA Scout and Lunar Flashlight will minimize development costs
  - Sail sized to meet propulsive requirements for both missions
  - Will additionally provide reflector for Lunar Flashlight science
  - Common elements include booms, materials, packaging, deployment and control systems

- Will seek commercial partner to license the sail technology for future NASA and commercial missions:
  - Exploration (additional NEA's)
  - Science (Planetary, Heliophysics)
  - Resource Identification (commercial)
- MSFC has Space Act Agreement with the Planetary Society for lessons learned on their LightSail Project



Cubesat Program Management

- SMD will fulfill its responsibility by providing value-added standard services to the PI as follows:
- NASA Project Manager is a member of the PI's project team.
  - Provide mission management to PI team throughout project life cycle with programmatic, technical, and launch assistance;
  - Facilitate mission while mitigating development risks associated with other sub-orbital programs of a 80% mission success flight rate.
  - Project Manager to recommend courses of action and help obtain government resources when requested.
  - Provide a mission library, including essential documentation, to help PI Team.
  - Provide mission oversight through informal reporting.
  - Provide project advocacy to NASA HQ and coordinate NRA funding
- The Program Office will arrange I&T facilities as needed for universities.
- The Program Office will assist the PI with services and guidance to PI team as requested.

Coordination with the Small Spacecraft Community

Annual Small Satellite Conference
Utah State University
- NASA Town Hall Meeting (STMD, SMD, HEOMD)
- Exhibits and presentations

Annual Cubesat Developers Workshop
California State Polytech
- Exhibit and presentations

Annual Government Cubesat Technical Interchange
- NASA, NRO, AFRL, NRL, SMC, DARPA, etc.

Small Payload Rideshare Conference

NASA Small Spacecraft State of the Art studies

AFRL University Nanosat Program
- NASA participates in project reviews and offers launches

Small Satellite Market Assessment

- 92 Small Sats launched in 2013 (269% increase from 2012)
- 119 Small Sats were launched in 2014
- >200 Small Sats launched to date
  - 50% academia, 25% government (NASA, DoD, etc.), 25% private (Planet Labs)
- Small Satellite average growth rate was 37% per year from 2009-2013
- 55% of Small Sats launched to date have been for technology development, ~20% for science. This trend is reversing
- 2000-2750 small sats will be launched between 2014-2020.
  - 410-543 Small Sats will be launched in 2020

NASA CubeSat partnerships with industry

Competitive solicitations leading to contracts for technology development and space demonstrations:

- Small Spacecraft Technology BAA and NRA's:
  - Projects underway with Tyvak LLC, Aerospace Corporation, Aerojet, Busek, MSNW, and numerous subcontractors
- New solicitations planned for systems and spacecraft buses
- Numerous SBIR contracts for small spacecraft technology.

Recent HEOMD awards for deep space cubesats (Lockheed Martin, Busek)

SMD opportunities for instrument technology development and demonstration and new science missions.

Contracting with commercial launch providers and secondary payload integrators.

Planning Space Act Agreement opportunities to share NASA expertise with commercial nano-launch developers.