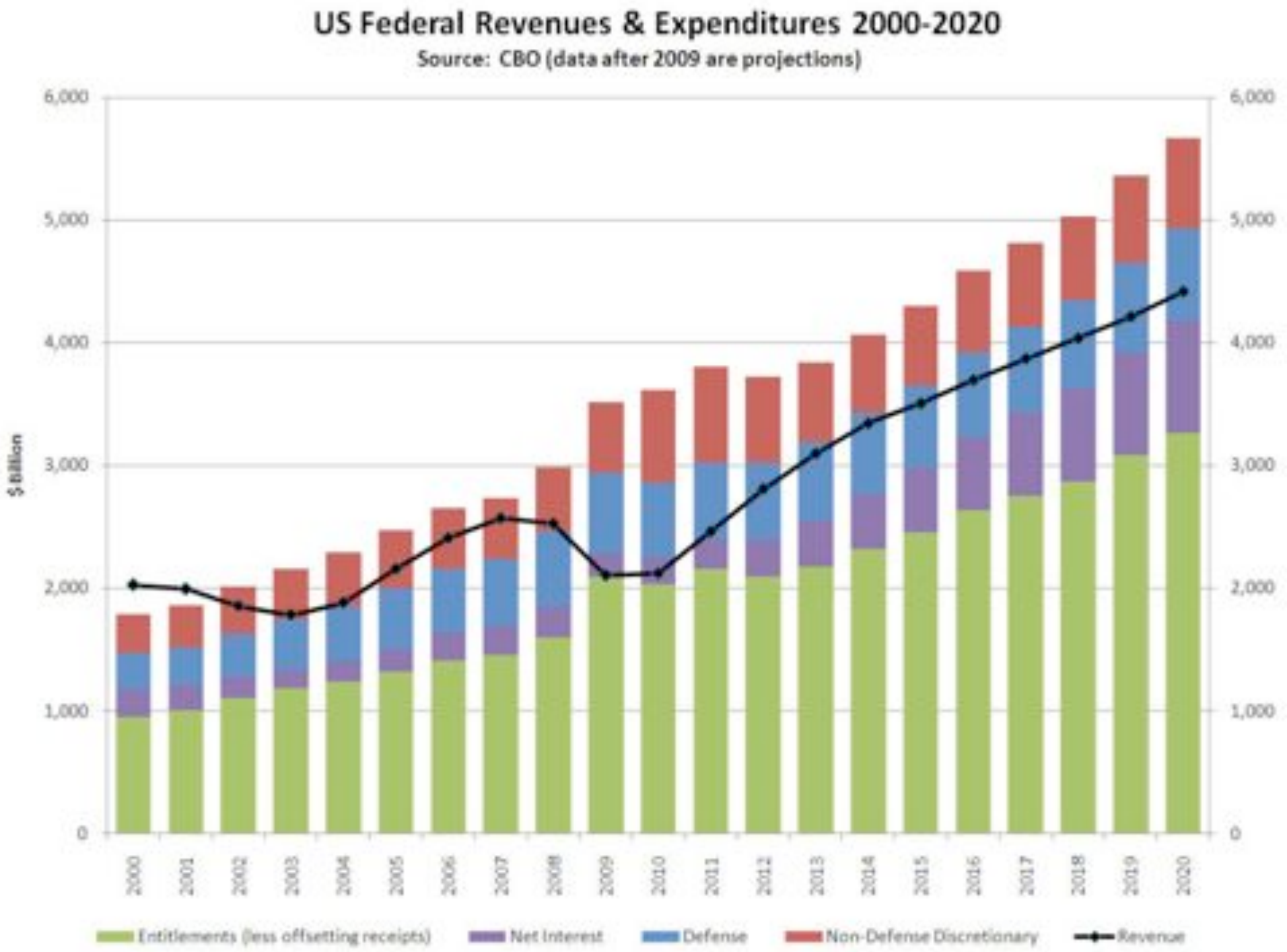
National Aeronautics and Space Administration

Ames

Discovery Innovations Solutions

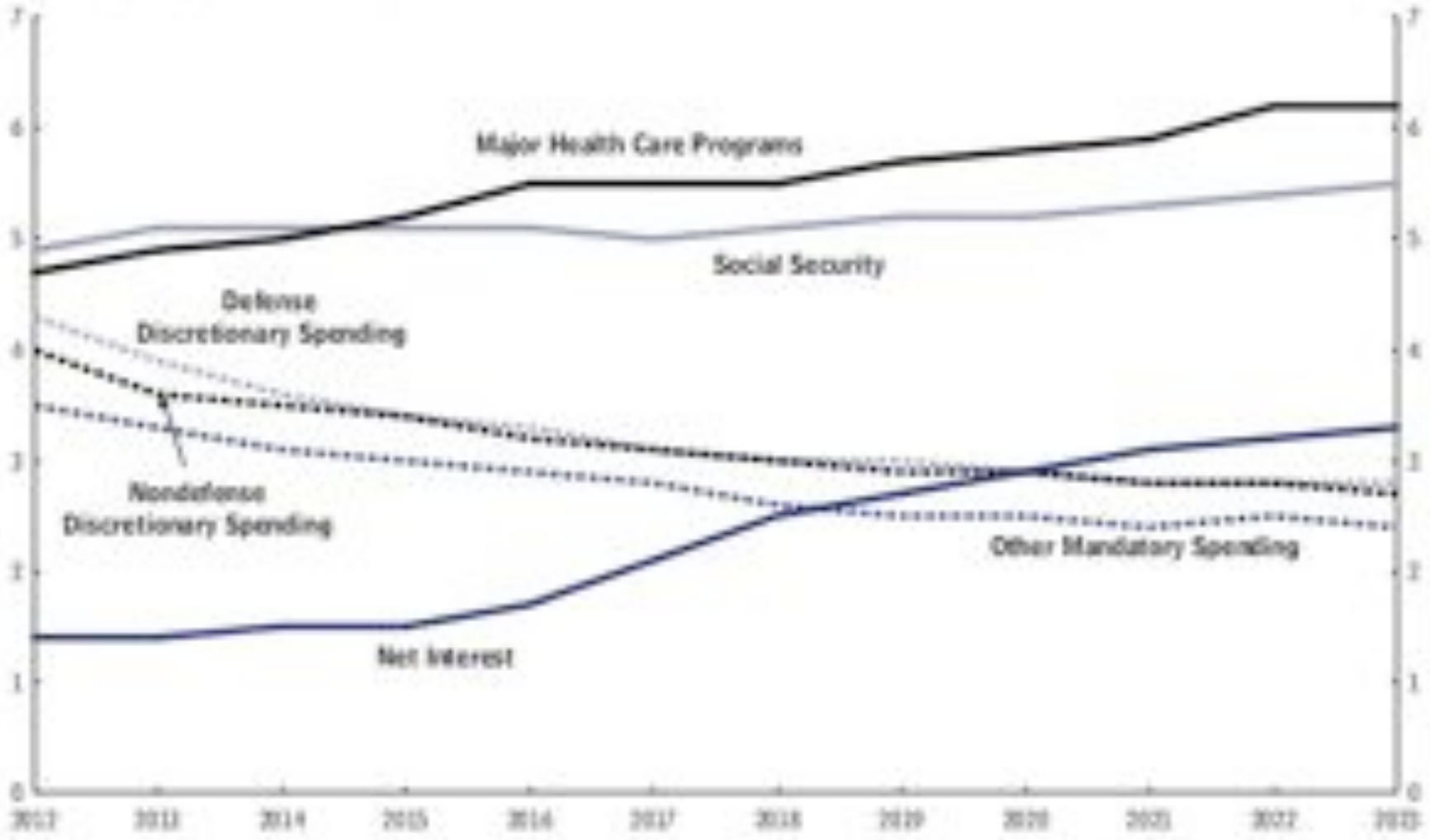
NASA and Small Satellite Research

- NASA's Interest in Small Satellites
- Nanosatellite Missions
- HQ Programs & Investments
- Future Missions & Opportunities
- Expanding Technology Portfolio


US Federal Revenues & Expenditures 2000-2020
Source: CBO (data after 2009 are projections)
$ Billion
6,000
5,000
4,000
3,000
2,000
1,000
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Entitlements (less offsetting receipts)
Net Interest
Defense
Non-Defense Discretionary
Revenue

Projected Spending for Major Budget Categories

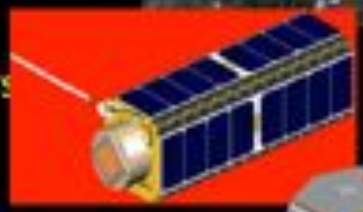
(Percentage of gross domestic product before BEA revisions)

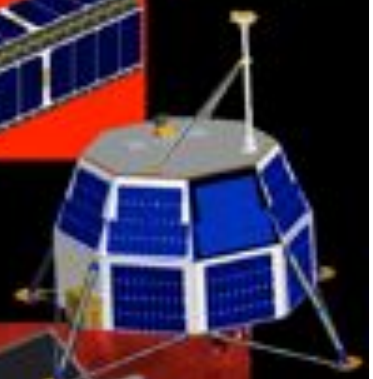


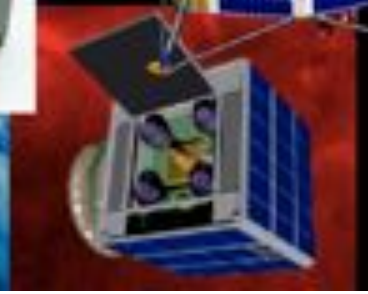
Spacecraft Mission Sizing

- Larger Spacecraft Excel at:
  - Large Diameter Sensors, Optics, Antennas, Detectors
  - Large Scale Investigations, Several Instruments
  - Lower calculated risk per individual mission
  - Lower cost per kilogram
  - Utilize "Proven Launchers"

- Smaller Spacecraft Excel at:
  - Simple Focused Missions, Science, Technology or Ops Demo
  - Unique Data Obtained In Near Term (Solar Cycle)
  - Short Duration Missions (<14 days for Landers, <2 years orbiters
  - Diversity of operating sites, landing sites or Orbits
  - Lower Cost Enables Increased Number Of Missions
  - Faster Learning Cycle, Lead to Lower Costs
  - If New Technology Sooner, Lowers Cost of Flagship Missions
  - Smaller Teams, Fewer Interfaces, Improved Collaboration

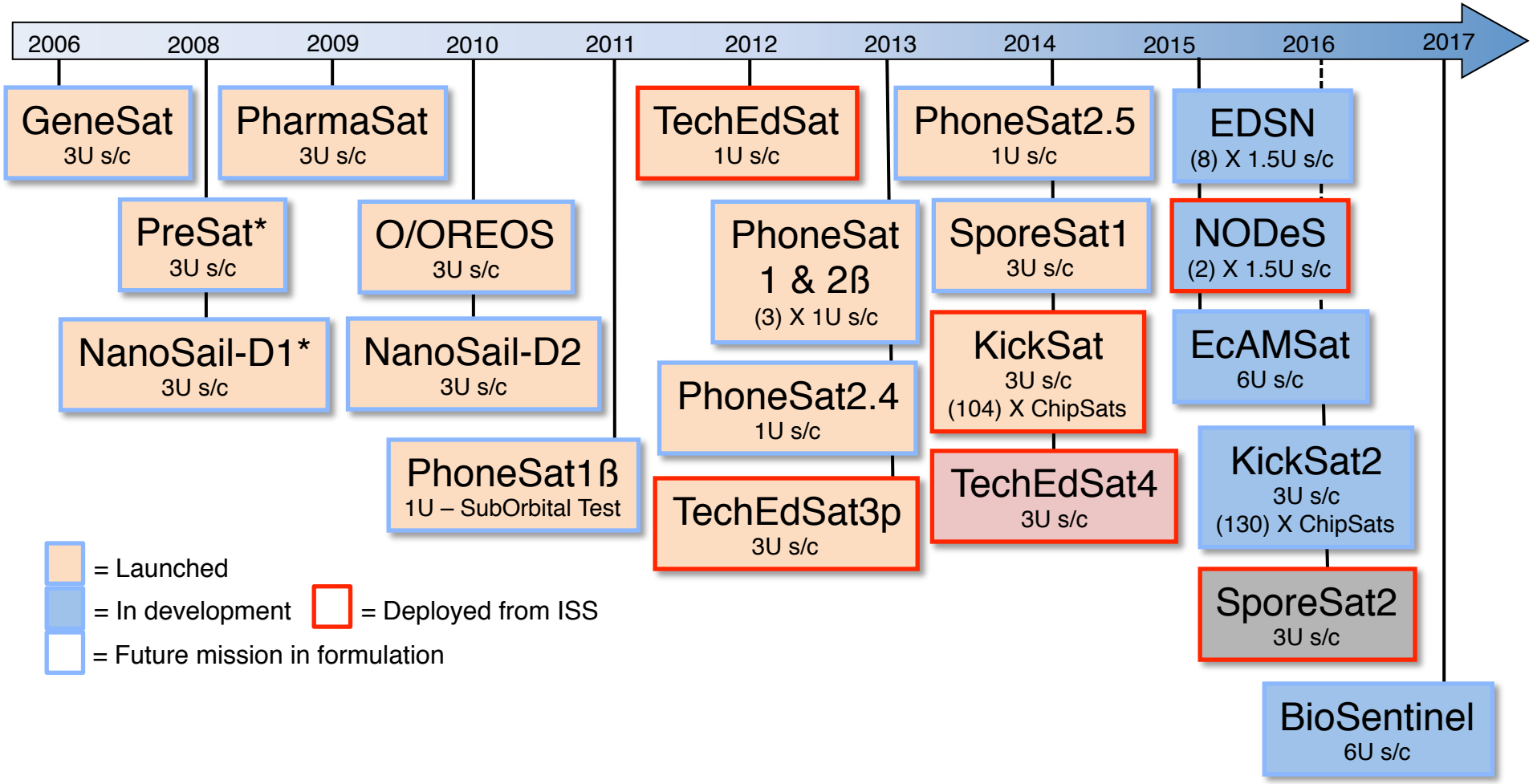






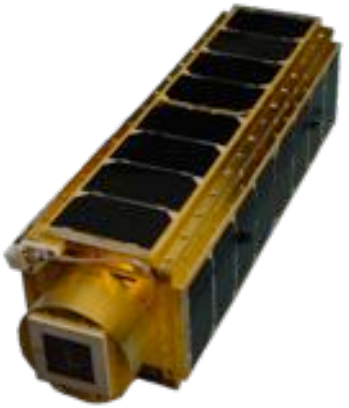
ADVANCES IN MINIATURIZATION ARE CLOSING THE GAP!

Nanosat Missions



Space Biology Nanosats: *Testing Life in Space*

Validating and Enhancing ISS biological testing

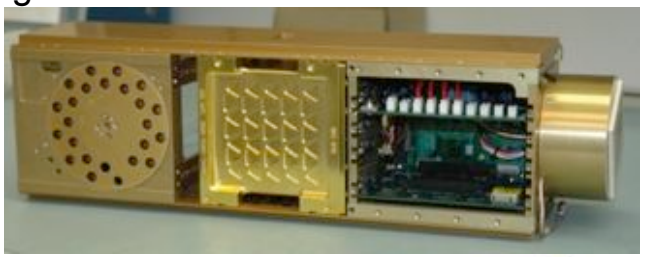


PharmaSat

- 3U Cubesat, launched May 2009, full mission success, 2U Biology payload
- Grew & characterized **yeast (*S. cerevisiae*);** tracked metabolic activity in 48 *μ*wells

O/OREOS

- 3U Cubesat, launched November 2010, full mission success, 2 payloads
- Demo'd satellite bus & payload instrument functionality > 3.5 years in high-rad 15x ISS

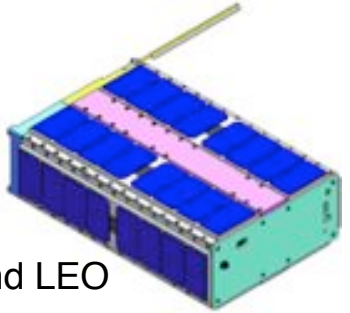


SporeSat 1 & SporeSat 2 (ISS deployed)

- 3U Cubesat, launched April 2014, 2nd spacecraft in Fall 2014
- Demonstrated growth of spores in gel medium, in variable-g

EcAMSat

- 6U Cubesat, launch ~ Spring 2015, 3U Biology payload
- Demonstrating *e Coli* antimicrobial resistance changes due to radiation and *μ*gravity

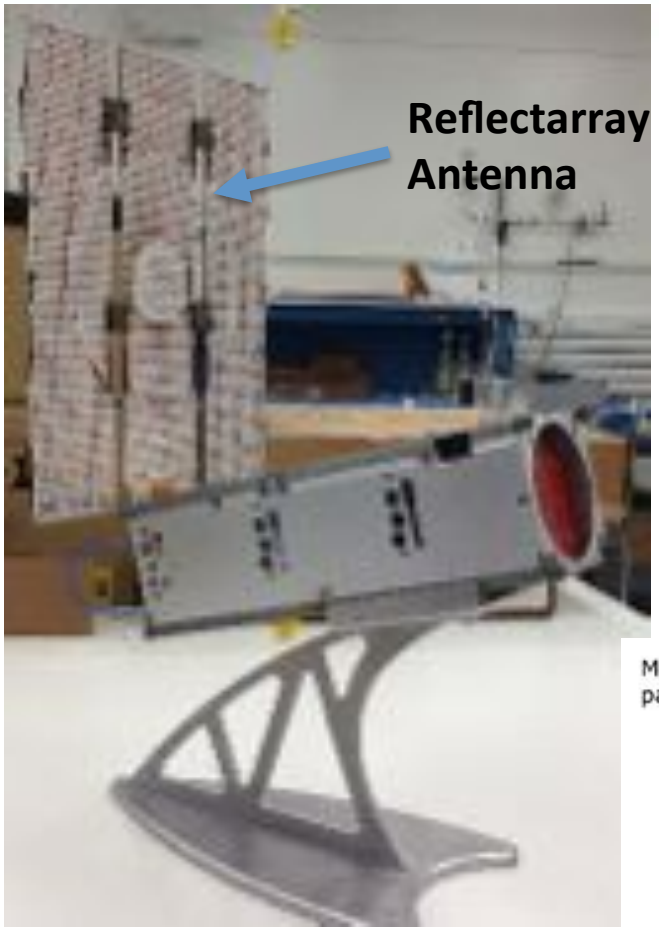


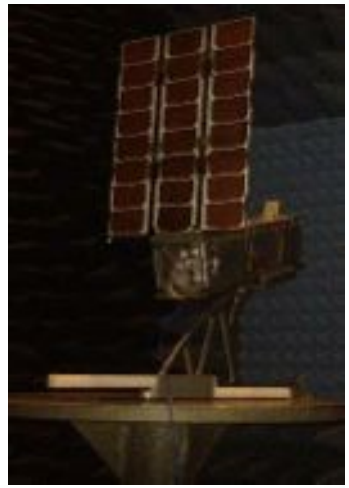
BioSentinel

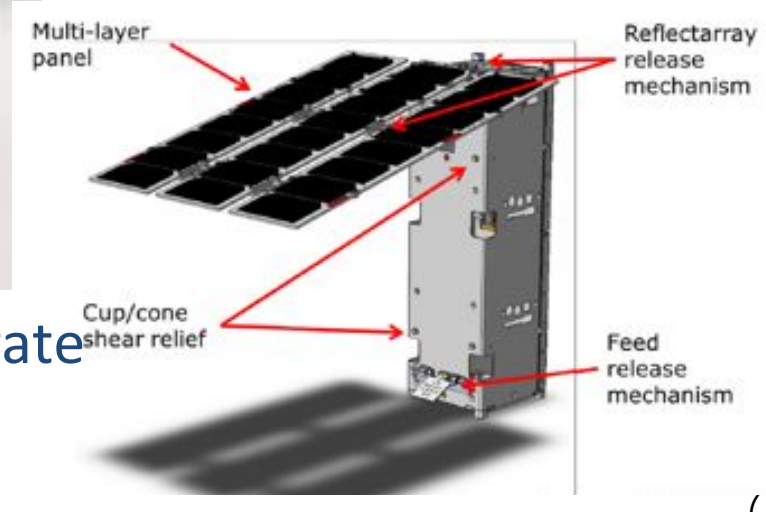
- 6U Cubesat, launch ~ Fall 2018 on a Lunar mission , 4U Biology payload
- Demonstrate use of simple organisms as "biosentinels" to Inform of risks to humans beyond LEO

Integrated Solar Array and Reflectarray (ISARA) Tech Demo

Falcon 9 – FormoSat-5
(NET DEC 2015)



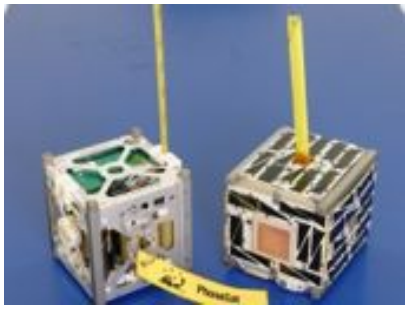




JPL Project – demonstrate
Ka Band downlink
Up to 100 Mbps

PhoneSats/EDSNs: *COTS Tech Demonstrators*

(Consumer-grade technology evaluation/validation for NASA use)



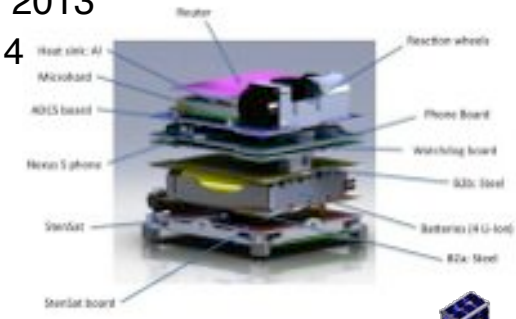
PhoneSat

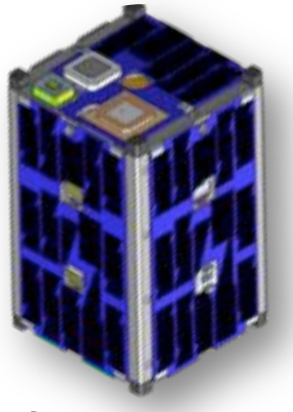
PhoneSat 1: First Phone-based spacecraft

- 2 x 1U Cubesats, Actual Nexus S phones as full Cubesat
- Launched April 21, 2013 on Antares-1. Achieved full functionality

PhoneSat(s) 2ß, 2.4, and 2.5

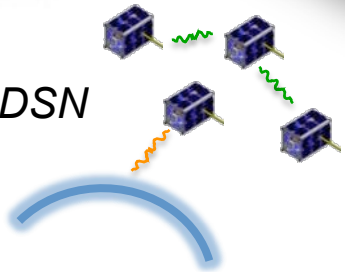
- 1U Cubesats, avionics derived from Nexus S Phone
- PhoneSat 2ß Launched April 21, 2013 on Antares-1
- PhoneSat 2.4 launched on a Minotaur 1 – ELaNa 4 in Nov 2013
- PhoneSat 2.5 launched on SpaceX – ELaNa 5 in April 2014





EDSN: First Nanosat Swarm

- Phonesat as core of 8 x 1.5U Cubesats,
- EDSN Swarm satellites using PhoneSat 2 components



EDSN

NODeS: ISS Nanosat Swarm demonstrator

- 2 EDSN Nanosats with Advanced Software deploying off of ISS

Technology Demo Timeline

2013	2014	2015	2016

Phonesat 1/2b
April 2013

Phonesat 2.4 & 2.5
November 2013 & April 2014

2012 → March 2014 **EDSN** → Oct 2015

April 2014 **Nodes** → Nov 2015

2013 → March 2015 **OCSD** → Aug & Dec 2015

2013 → Aug 2015 **CPOD** → Dec 2015

2013 → Aug 2015 **ISARA** → Dec 2015

Maraia
(Suborbital) → Aug 2015

Propulsion Pathfinder & Isat

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

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CLSI

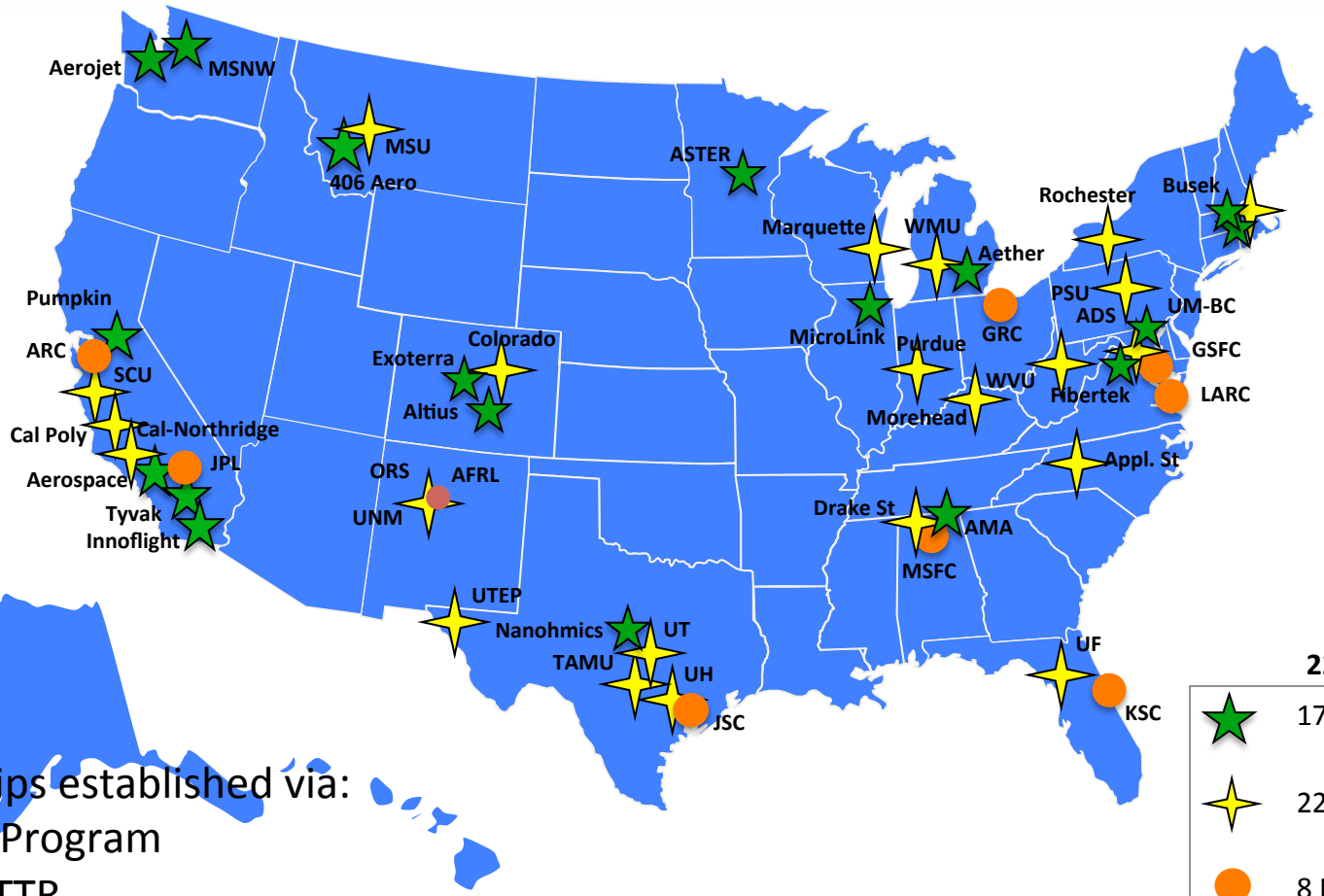
Cubesat Launch Initiative

14 CubeSats selected from 12 US states and will fly as auxiliary payloads aboard rockets planned to launch in 2016, 2017 and 2018.

As part of the White House Maker Initiative, NASA is seeking to leverage the growing community of space-enthusiasts to create a nation that contributes to NASA's space exploration goals.

The aim is to launch 50 small satellites from all 50 US states in the next five years.

Small Spacecraft Technology
Nationwide Participants and Partners



Partnerships established via:

- ELaNA Program
- SBIR/STTR
- MOU with other Gov't Agencies

www.nasa.gov/smallsats


LEO
L2
L4
L3
L1
L2
L5
EXPANDING OUR KNOWLEDGE WITH CUBESATS

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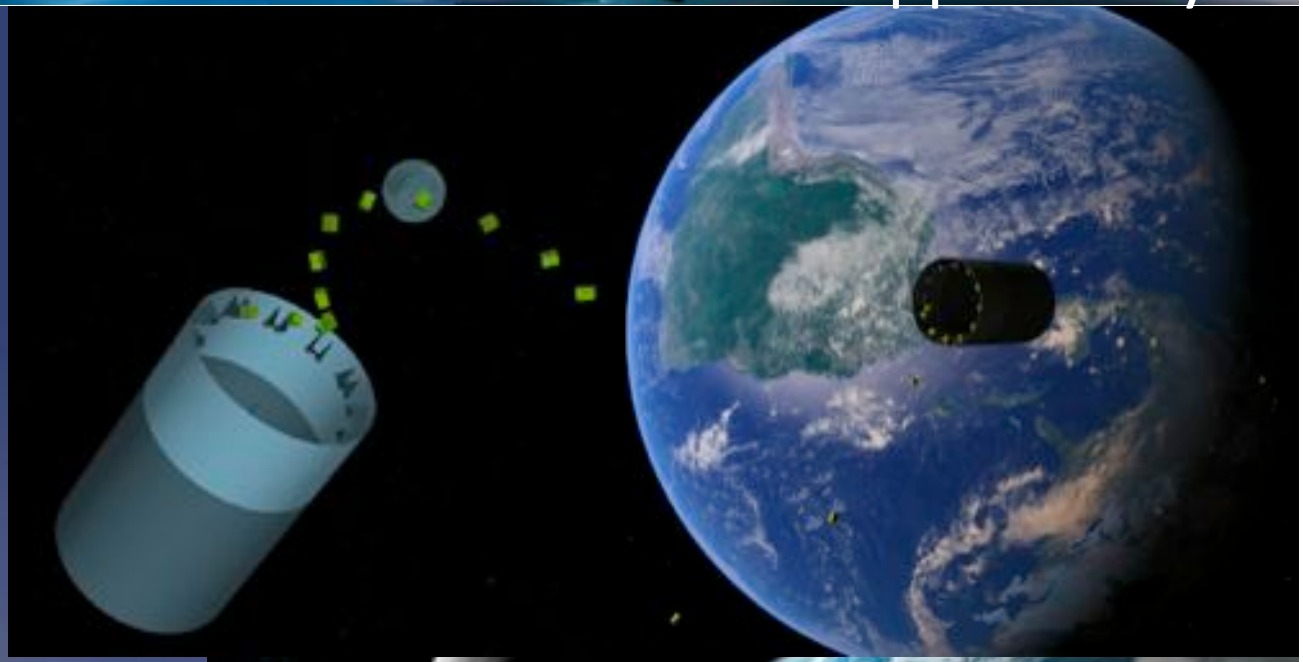
Deep Space Opportunity



Cubesats Beyond LEO

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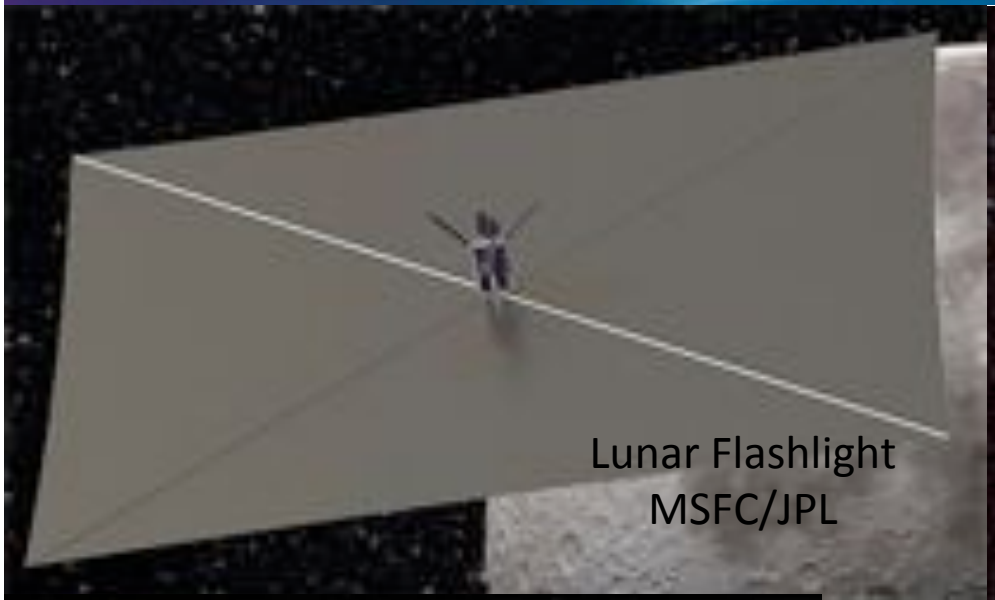

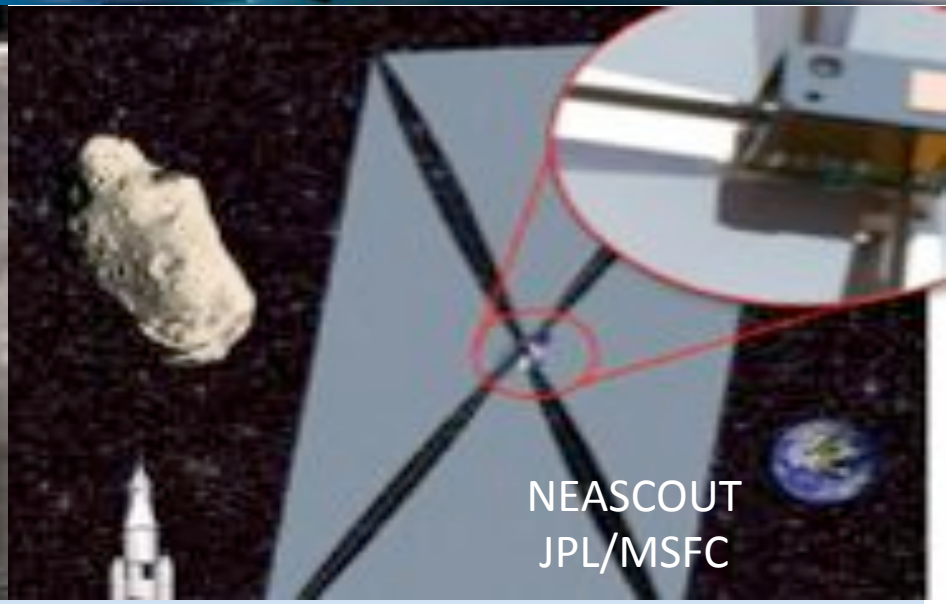

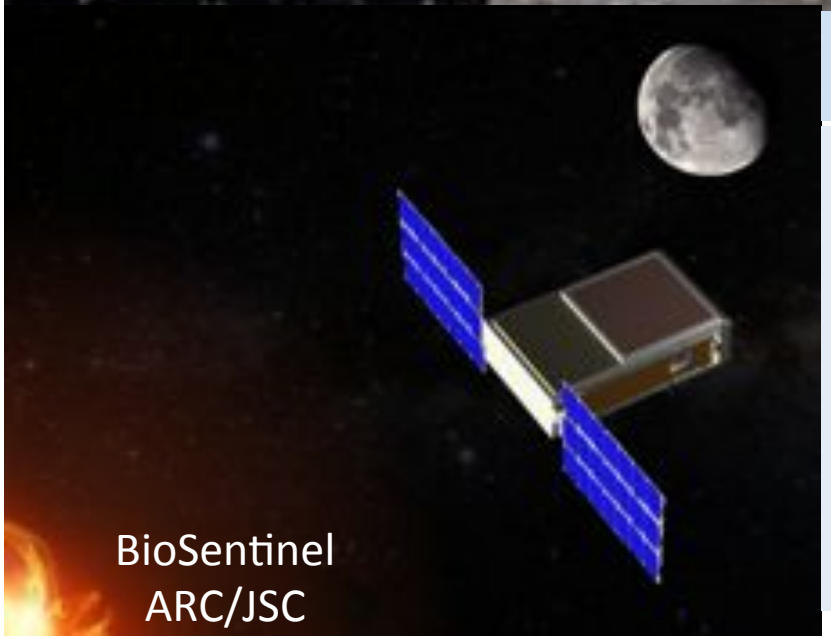

SLS EM-1 Opportunity LRD 2018

HEOMD/AES funded missions.

- Lunar Flashlight – Locate ice deposits in the Moon's permanently shadowed craters.
- NEA Scout – Flyby/Rendevous and characterization of one NEA that is a candidate for a human mission.
- BioSentinel- Study Radiation Induced DNA of live organisms in cis-lunar space.

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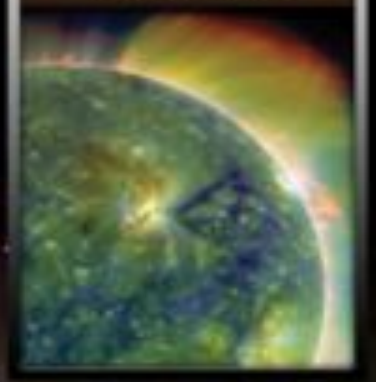
Space Missions Directorate

Earth

To develop a scientific understanding of Earth's system and its response to natural or human-induced changes, and to improve prediction of climate, weather, and natural hazards.

- Atmospheric Composition
- Weather
- Carbon Cycle & Ecosystems
- Water & Energy Cycles
- Climate Variability & Change
- Earth Surface & Interior

Heliophysics



Understanding the Sun, Heliosphere, and Planetary Environments as a single connected system

- Heliosphere
- Magnetospheres
- Space Environment

Planets

Observation and discovery of our solar system's planetary objects. ...strategy based on progressing from flybys, to orbiting, to landing, to roving and finally to returning samples from planetary bodies

- Mars Program Planning

Astrophysics

Discover how the universe works, explore how the universe began and developed into its present form, and search for Earth-like planets.

- Planets Around Other Stars
- The Big Bang
- Dark Energy, Dark Matter
- Stars
- Galaxies
- Black Holes

SMD

- + Helio-1 "ELFIN-STAR" - Principal Investigator: V. Angelopoulos, UCLA ELFIN-STAR seeks to understand storm-time precipitation of radiation belt relativistic electrons and determine if electromagnetic ion cyclotron waves are responsible for the precipitation.
- + Helio-2 "CuSPP" - Principal Investigator: M. Desai, Southwest Research Institute CuSPP will study solar particles over Earth's poles to provide space weather relevant observations through combined interplanetary energetic particle and suprathermal source population observations at high cadence.
- + Helio-3 "TBEx" - Principal Investigator: R. Tsunoda, SRI, NASA's Goddard Space Flight Center TBEx will significantly improve the understanding of the role of atmospheric gravity waves on the formation of equatorial plasma bubbles.
- + Helio-4 "MinXSS" - Principal Investigator: T. Woods, LASP, NASA's Goddard Space Flight Center MinXSS will improve understanding of solar spectral irradiance to improve modeling capabilities and reduce uncertainty regarding where in the upper atmosphere of Earth solar photon energy is deposited.
- + Helio-5 "SORTIE" - Principal Investigator: G. Crowley, Atmospheric and Space Technology Research Associates SORTIE will investigate the underlying causes behind the appearance of plasma structures in the F-region of Earth's ionosphere, leading to equatorial plasma bubbles, and the evolution of these structures after formation.
- + Earth-1 "IceCube" - Principal Investigator: D. Wu, NASA's Goddard Space Flight Center IceCube is a sub-millimeter wave radiometer to advance understanding of ice clouds and their roles in climate change.

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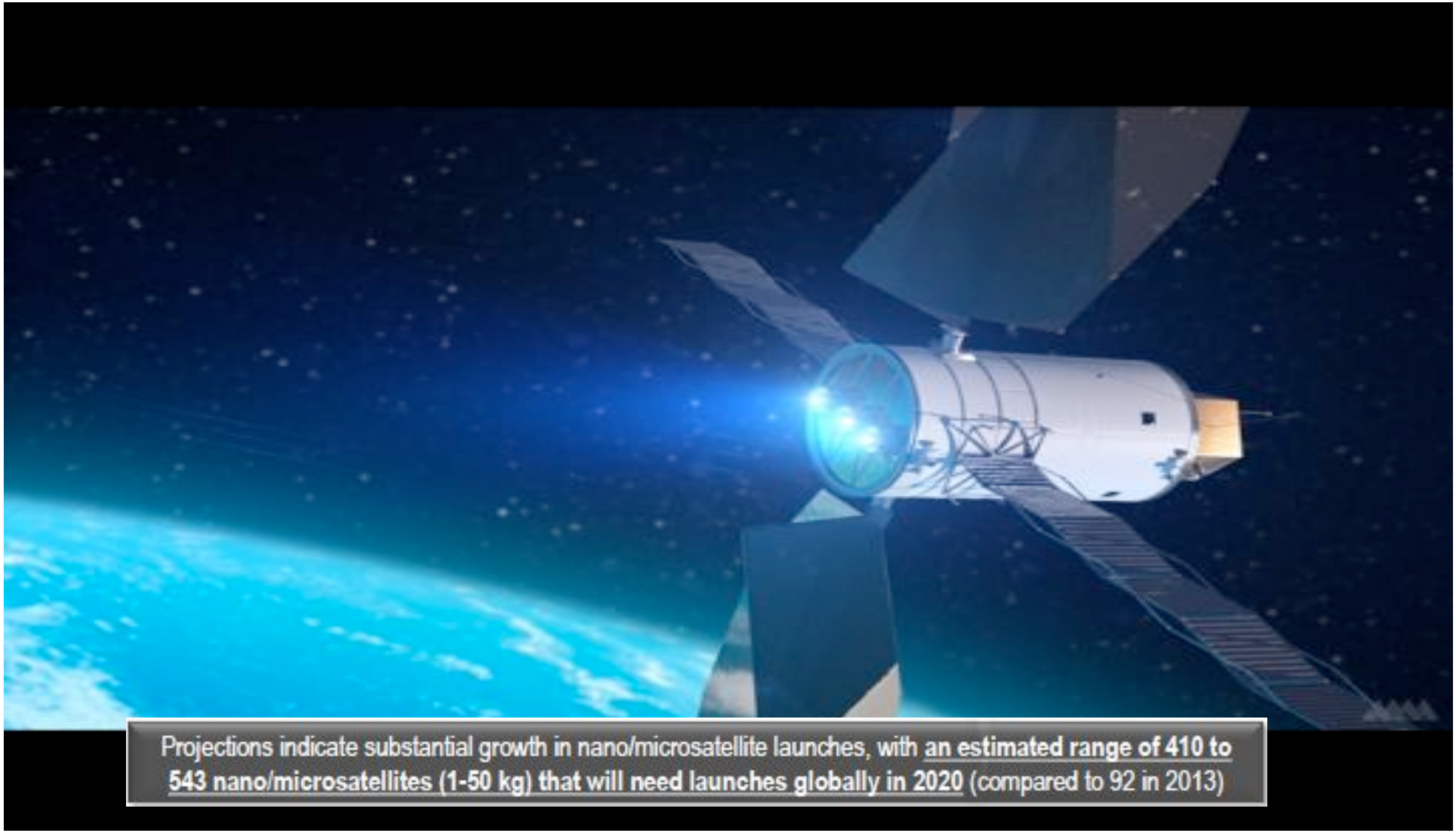
HEOMD/AES NextSTEP Broad Agency Announcement.

SMD – Small Innovative Mission for Planetary Exploration (SIMPLEX)

- What is needed
- Technology areas
- Products to support/enhance NASA Subtopic
- Missions (planned and projected
- Tools
- Efficient LC dev

Projections indicate substantial growth in nano/microsatellite launches, with **an estimated range of 410 to 543 nano/microsatellites (1-50 kg) that will need launches globally in 2020** (compared to 92 in 2013)

ENABLING FUTURE MISSIONS & EXPANDING TECHNOLOGY PORTFOLIO



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National Aeronautics and
Space Administration
NASA
Small Spacecraft
Technology Program
Director, Andres Martinez
www.nasa.gov/smallsats

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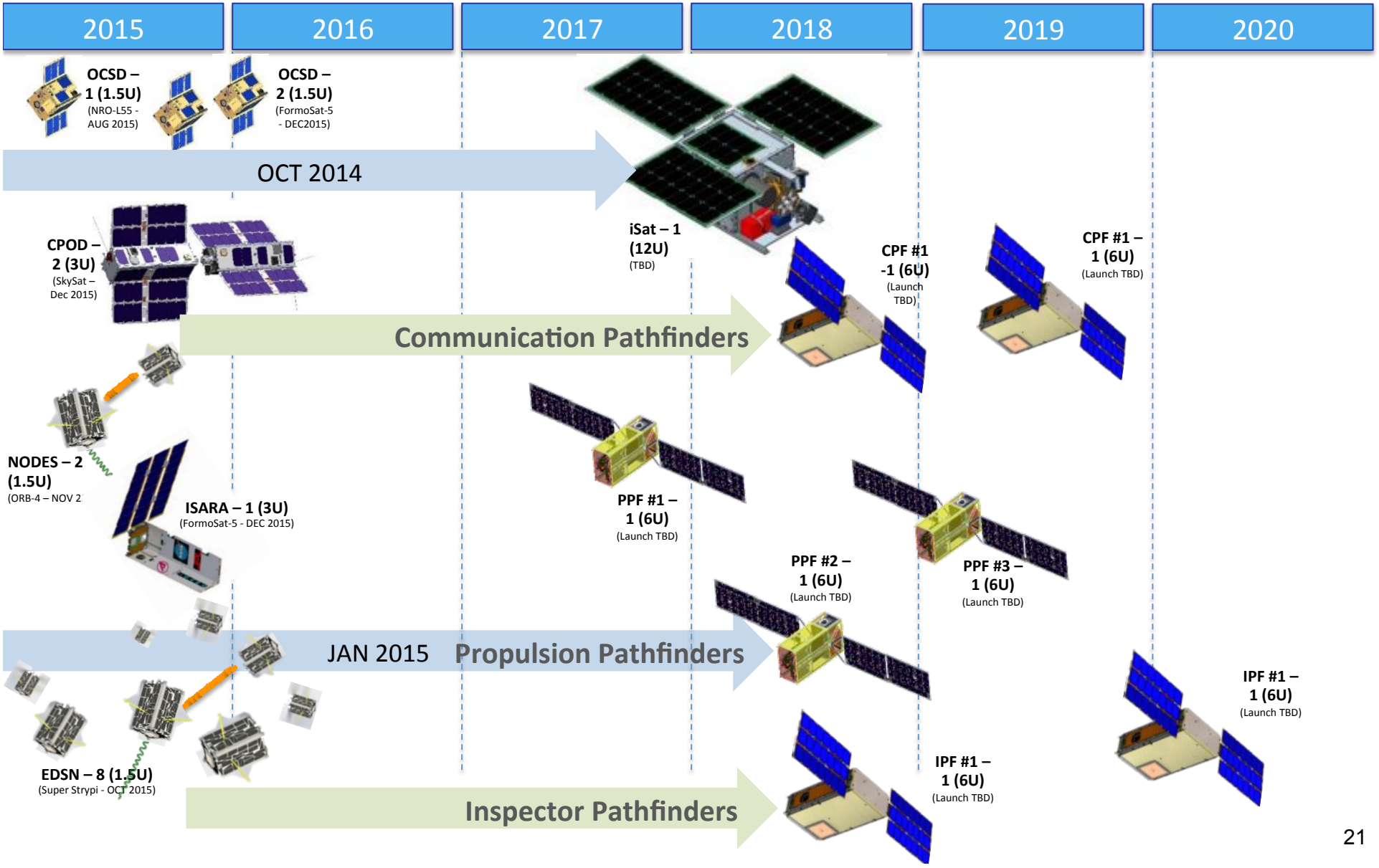
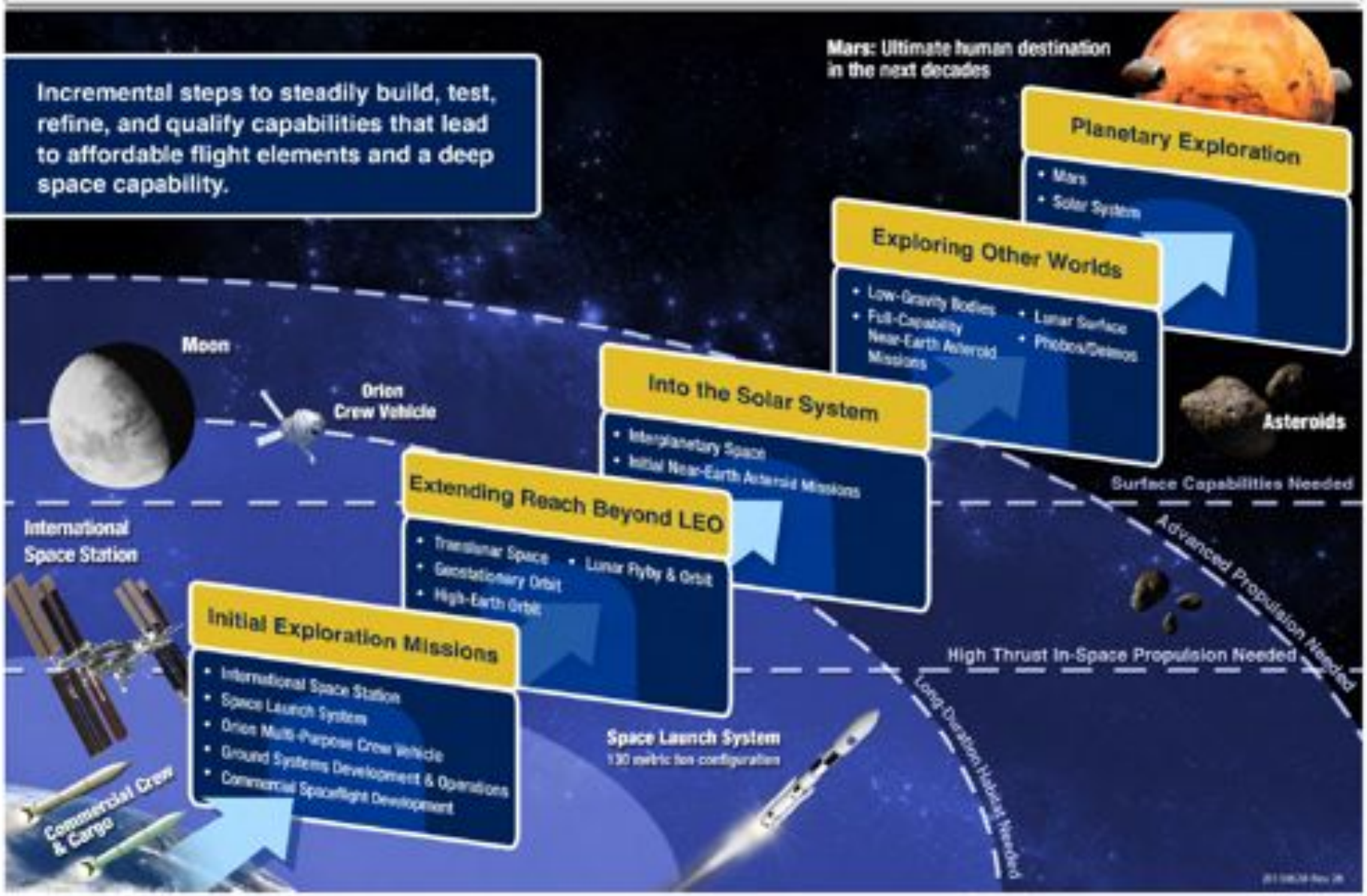
SSTP
Flight Projects: CY 2015-2020



Capability Driven Framework



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SPHERES RINGS

Visit us @ http://www.nasa.gov/spheres

Follow us on Twitter @NASA_SPHERES

Synchronized
Position
Hold,
Engage,
Reorient,
Experimental
Satellites

Q. What does it do?

A. RINGS uses two large Electro-Magnets to move around the ISS by attracting and repelling the SPHERES with respect to each other instead of using the built in CO_2 thrusters. Additionally, RINGS are also able to wirelessly transfer power between each other.

Q. Why is it important?

A. Being able to move around without the need of a consumable fuel source is very important for deep space missions. Most spacecraft carry a limited amount of fuel. By using Electro-Magnetic propulsion we no longer have to worry about running out of fuel.

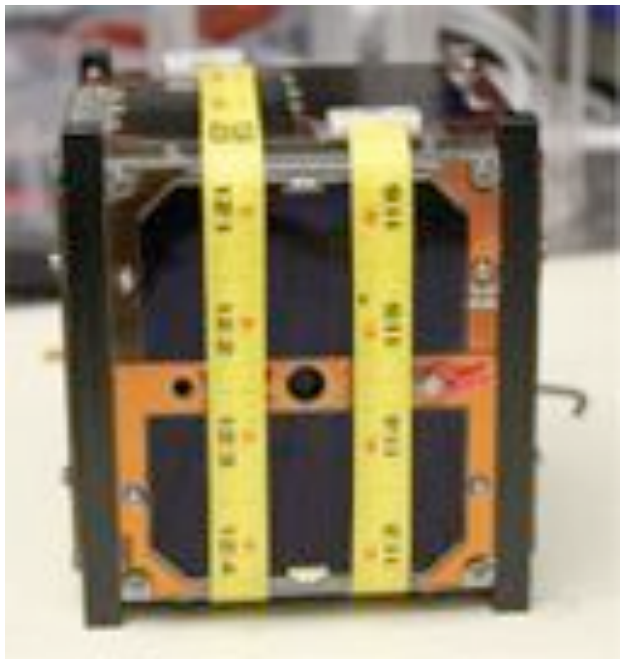
University of Maryland

SSL

Ames Research Center

DARPA

Aurora Flight Sciences



COVE

Earth Science Invest

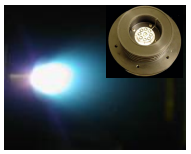
NASA's Earth Science Technology Office (ESTO) manages the development of a range of advanced technologies to meet future Earth science measurement requirements. ESTO technology investments attempt to address the full science measurement process: from instruments needed to make observations to data systems and information products and tools that make those observations useful.

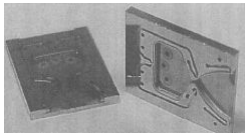
EVI-3 - $31M Cubesat Opportunity

This solicitation calls for proposals for complete PI-led science investigations requiring spaceflight instrument or CubeSat(s) development. The term "complete" encompasses investigation phases from project initiation, through development and science operations, to scientific analysis of space based data. These spaceflight missions will be used to conduct innovative, integrated, hypothesis or scientific question-driven investigations addressing pressing Earth system science issues.

Spacecraft Technologies Development

- Advanced Bus Architectures
  - Plug and Play
  - Autonomous Operations
- Data Handling
- Communications
- Guidance, Navigation and Control
  - MEMS Accelerometers and Gyroscopes
  - Miniaturized GPS Devices
  - Propellantless Attitude Control
- Multisatellite Operations
  - Formation Flying/Constellations
- Power
  - Long-life, High-density, Scalable Power Storage
  - Deployable Solar Arrays
- Structure
  - Evolvable, Reconfigurable Satellites
- Thermal Management
  - MEMS-based

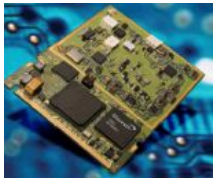

NanoThrusters


MicroPropulsion


High-Capacity, Lightweight Batteries

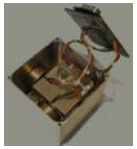

GPS Receiver


High-Performance, Low-Power Computing


5.8-GHz Transceiver


Sun Sensor


Mini Star Tracker


Nano Reaction Wheels


Ultralight-weight IMU

Enabling Science Missions:

Precision Formation Flying

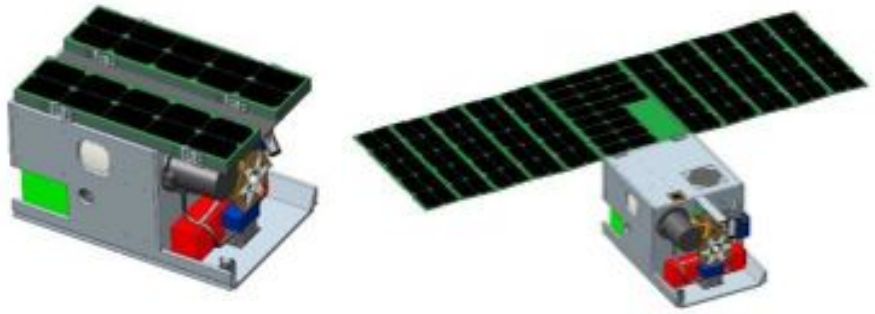
Remote Imaging: Earth/Lunar Science

Autonomous Satellite Maintenance

Space Physics & Astrophysics

Exploration: Lunar, NEOs, Comets

Iodine Satellite (iSAT)



Spacecraft Specifications

- Mass: 24kg
- Quantity: One 12U CubeSat
- Orbit: 700km initial orbit (SSO), 98.1880° incl.
- Size: 20cm x 20cm x 30cm
- Communication: S-Band

Mission Description

The iSAT Project is the maturation of iodine Hall technology to enable high ΔV primary propulsion for NanoSats (1-10kg), MicroSats (10-100kg) and MiniSats (100-500kg) with the culmination of a technology flight demonstration. The iSAT project has three major elements: iodine Hall technology development support, the iSAT flight demonstration and future technology risk reduction. In addition to the iodine Hall focus, this project recognizes the market growth potential for SmallSats and the gap in commercially off the shelf (COTS) options for higher capable spacecraft: higher power systems, additional thermal control, higher data rates, improved stability and attitude control, etc.

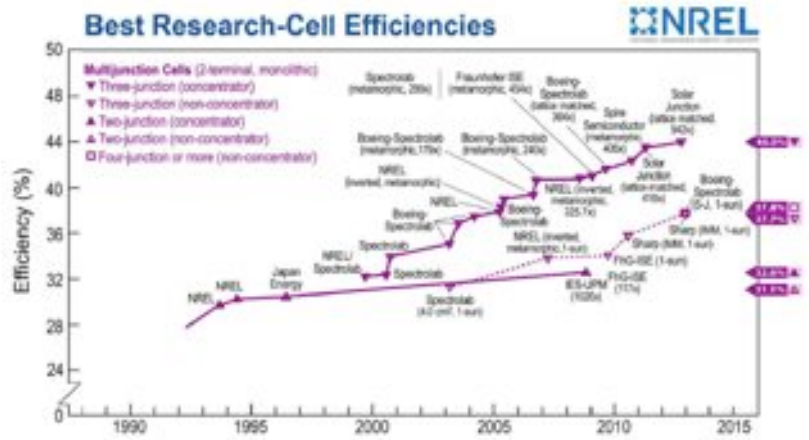
LCCE - $12,757K

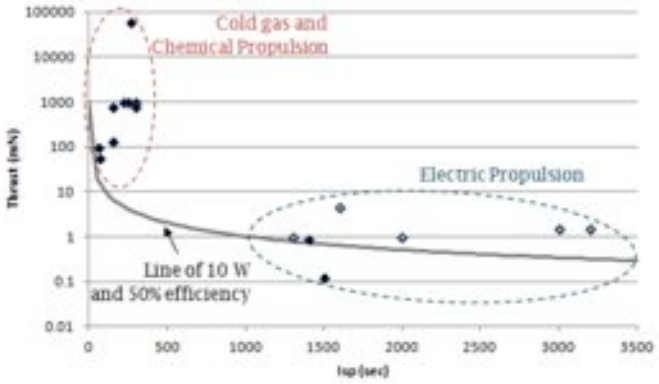
Status

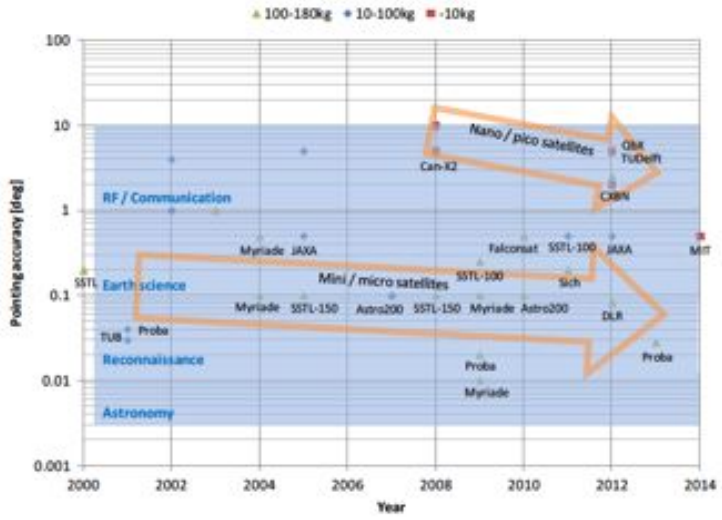
The iSAT project completed it's preliminary design review in December of 2014 and is working towards CDR in the summer of 2015. The current design and analysis cycle is showing positive margins in all areas and development is on plan.

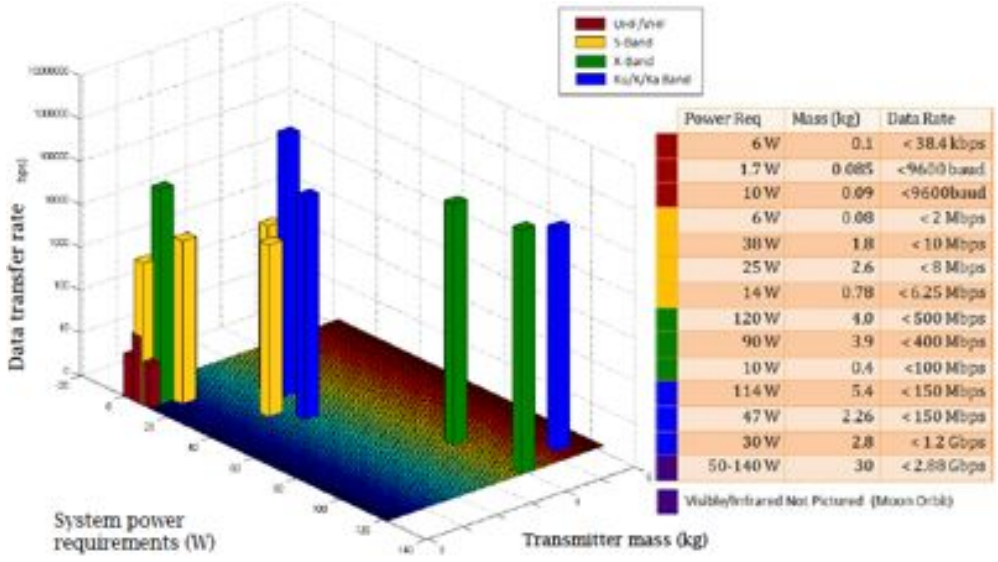
Critical Milestones

ATP	SRR	PDR	CDR	FHR	FRR/ORR	Launch	Mission Ops	Mission Duration	Project Closure
7/18/14	7/28/14	12/9/14	TBD	TBD	TBD	11/1/2017	11/15/2017	6 Months	5/25/2018


Best Research-Cell Efficiencies
NREL
Efficiency (%)
Multijunction Cells (2-terminal, monolithic)
Three-junction (concentrator)
Three-junction (non-concentrator)
Two-junction (concentrator)
Two-junction (non-concentrator)
Four-junction or more (non-concentrator)
1990
1995
2000
2005
2010
2015


Cold gas and
Chemical Propulsion
Electric Propulsion
Line of 10 W
and 50% efficiency
Thrust (mN)
Isp (sec)


100-180kg
10-100kg
-10kg
Pointing accuracy [deg]
Year
RF / Communication
Earth science
Reconnaissance
Astronomy
Nano / pico satellites
Mini / micro satellites
Can-X2
GIOVE-A
TUDelft
CIBN
Myriade
JAXA
Falconsat
SSTL-100
MIT
SSTL
SSTL-150
Astro200
Sich
DLR
TUB
Proba


Uhf/vhf
S-Band
X-Band
Ku/K/Ka Band
Data transfer rate
System power requirements (W)
Transmitter mass (kg)
Power Req
Mass (kg)
Data Rate
6 W 0.1 < 38.4 kbps
1.7 W 0.085 <9600 baud
10 W 0.09 <9600 baud
6 W 0.08 < 2 Mbps
38 W 1.8 < 10 Mbps
25 W 2.6 < 8 Mbps
14 W 0.78 < 6.25 Mbps
120 W 4.0 < 500 Mbps
90 W 3.9 < 400 Mbps
10 W 0.4 <100 Mbps
114 W 5.4 < 150 Mbps
47 W 2.26 < 150 Mbps
30 W 2.8 < 1.2 Gbps
50-140 W 30 < 2.88 Gbps
Visible/Infrared Not Pictured (Moon Orbit)

National Aeronautics and Space Administration

Ames

Discovery Innovations Solutions

Continued Development of Small Satellite Launch Capabilities

National Aeronautics and Space Administration

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Discovery Innovations Solutions

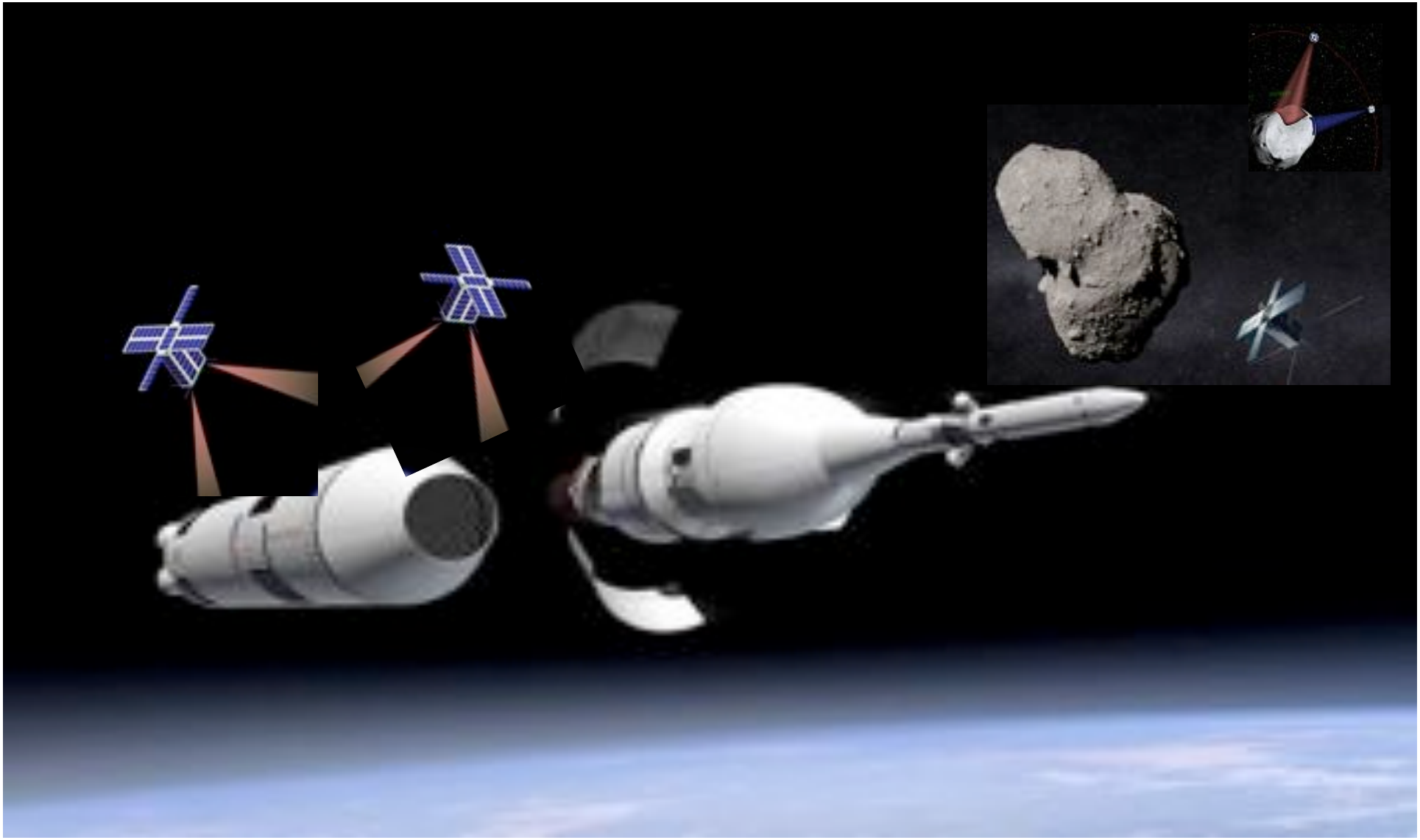
MISSION CONCEPTS

National Aeronautics and Space Administration

Ames

Discovery Innovations Solutions

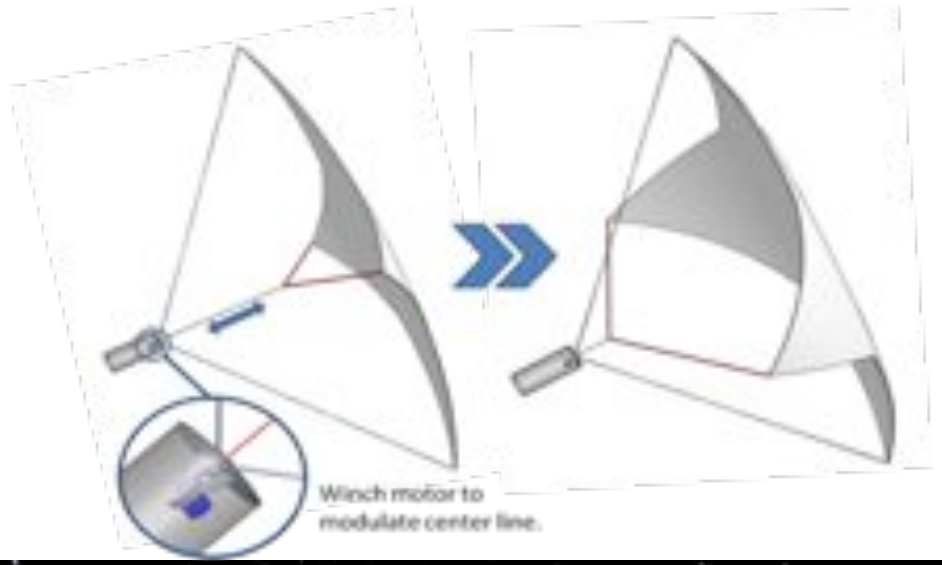
Proximity Operations & NEA Surveys



National Aeronautics and Space Administration

Ames

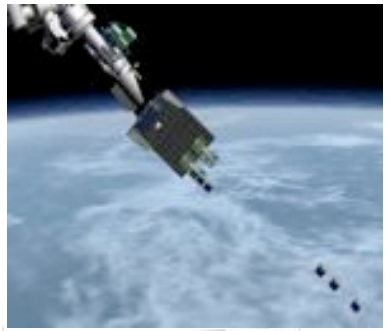
Discovery Innovations Solutions



SAMPLE RETURN & EDL TECHNOLOGIES

TechEdSats: *Re-Entry Technology Demonstrators*

ISS Downmass and EDL demonstrators

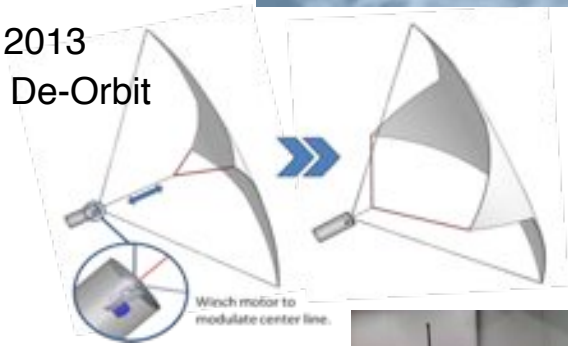


TechEdSat-1: First U.S. & NASA CubeSat launched from ISS

- 1U Cubesat at 1.2kg, Launched July 21st 2012, Deployed from ISS October 4th 2012
- Passed out of JAXA's ISS airlock, deployed from JAXAs robotic arm
- Standardized the Process for ISS Cubesat Deployments now used by Nanoracks

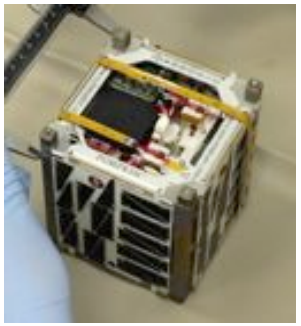
TechEdSat-3p: First 3U Nanosat from ISS

- 3U Nanosat, Launched August 4 2013 (HTV-4), ISS deployed on Nov 19, 2013
- First sub-scale Exo-Brake test; Iridium downlink/uplink test; validation burned up during Earth Re-entry



TechEdSat-4: Deploying from ISS summer 2014

- 3U Nanosat, to be launched ~July 1st 2014 on Orbital's Orb2 to ISS
- To be deployed from Nanoracks Cubesat Launch system
- Reflight of TechEdSat-3p Exobrake, updated Iridium & GPS hardware



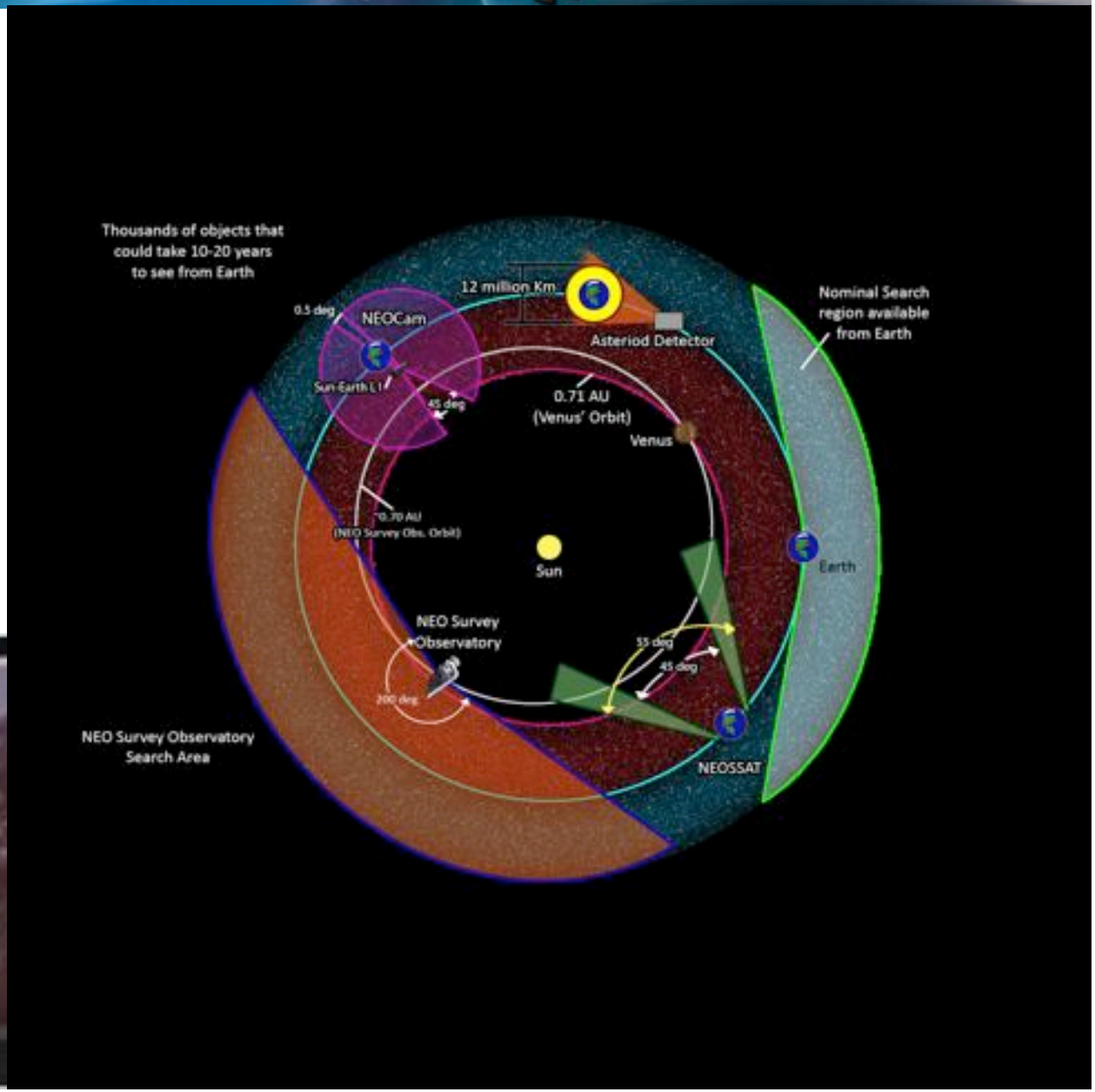
National Aeronautics and Space Administration

Ames

Discovery Innovations Solutions

Planetary Defense

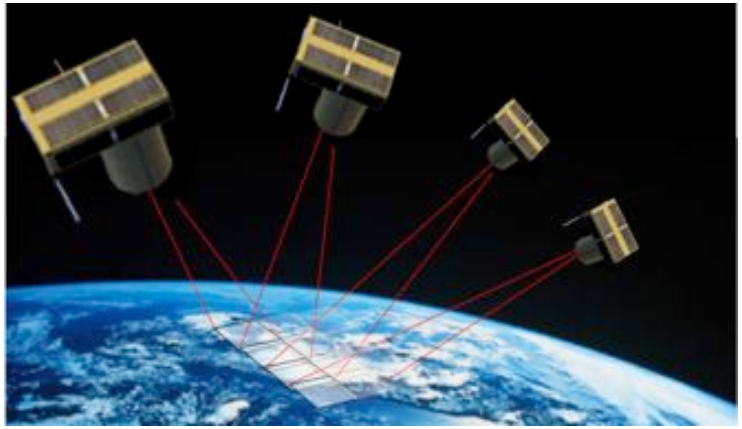
Asteroid Detection Investigation & Impact Mitigation



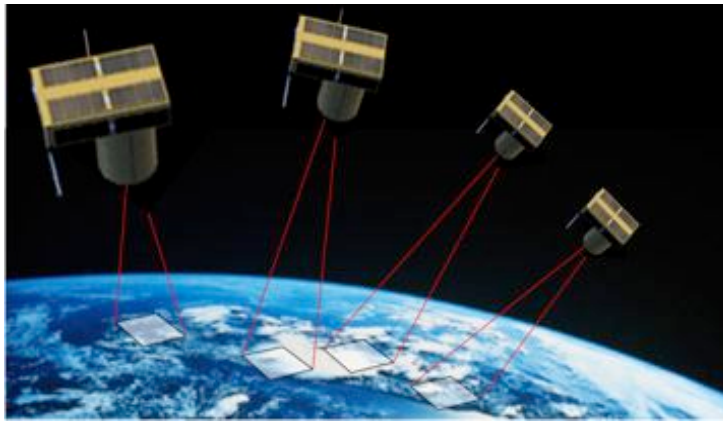
Earth Science Observations

Super Resolution

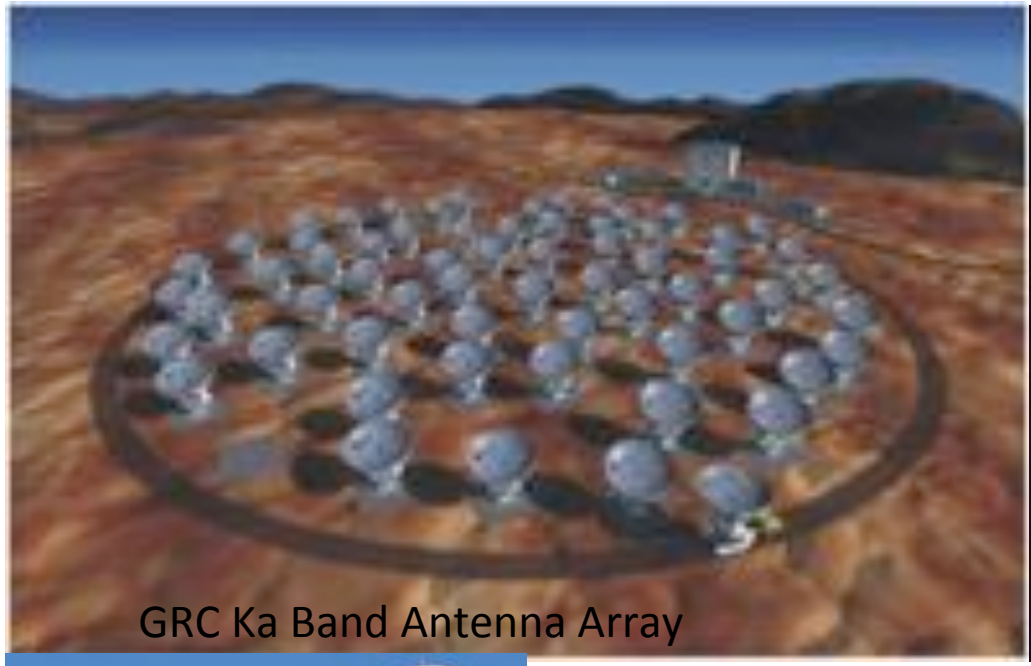
Mosaic



Simultaneous Multi-point



Multi-task


GRC Ka Band Antenna Array

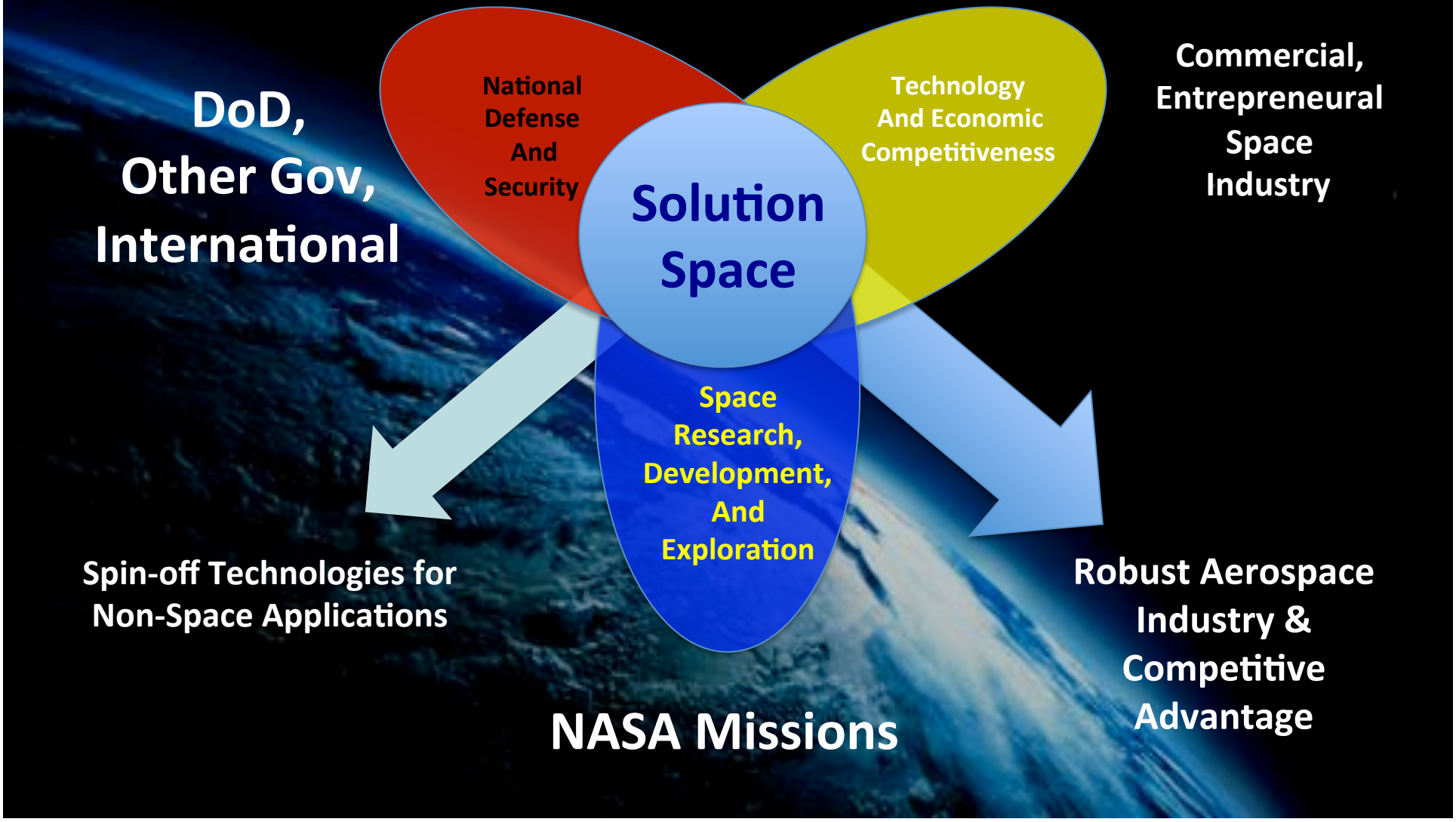

DSN Goldstone 70m


Morehead State 20m

Enhanced Communication and Tracking Stations to support Multiple missions.

Technology and Innovation Strategy

… *Addressing Global Needs*



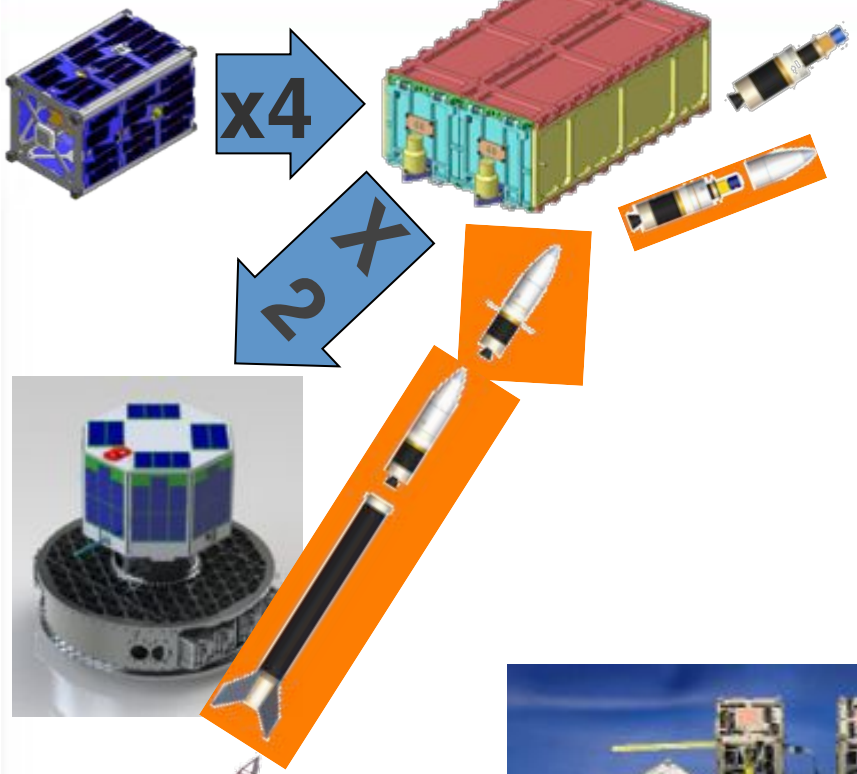
http://www.nasa.gov/smallsats

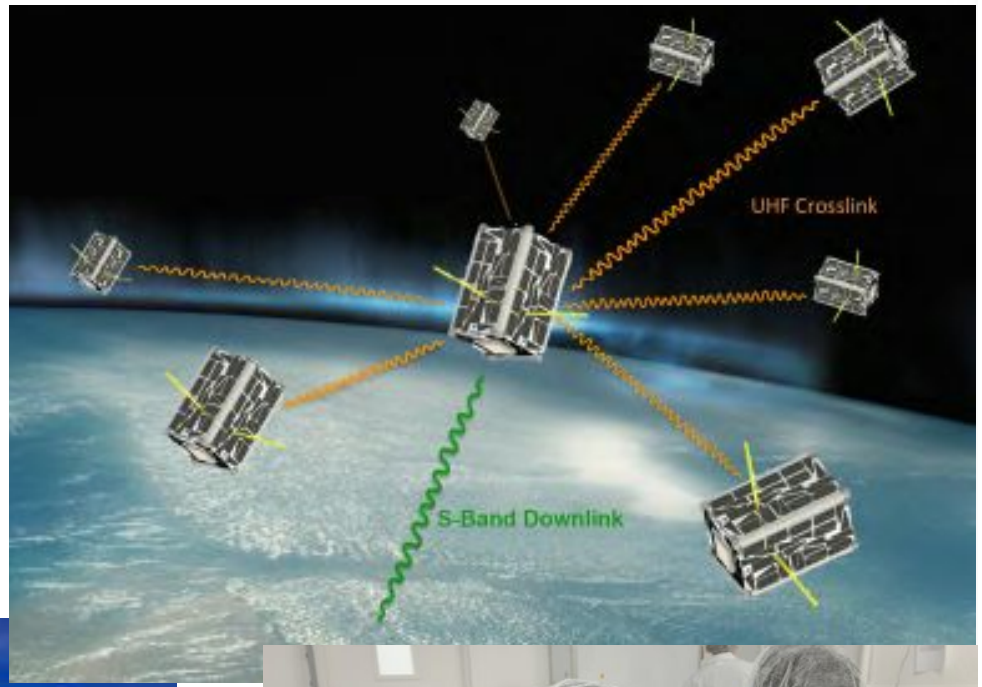
http:// www.nasa.gov/spheres

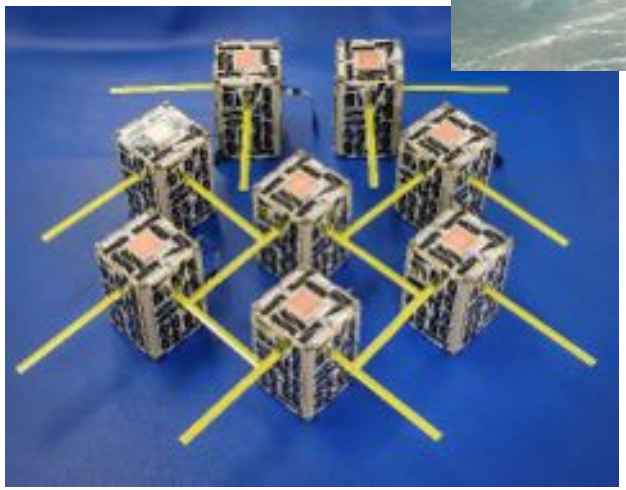
http://www.nasa.gov/sporesat

Andres.Martinez@nasa.gov

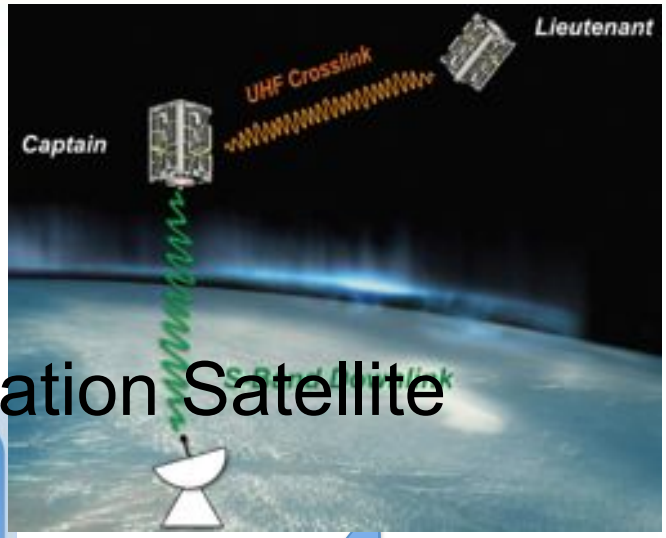
Edison Demon



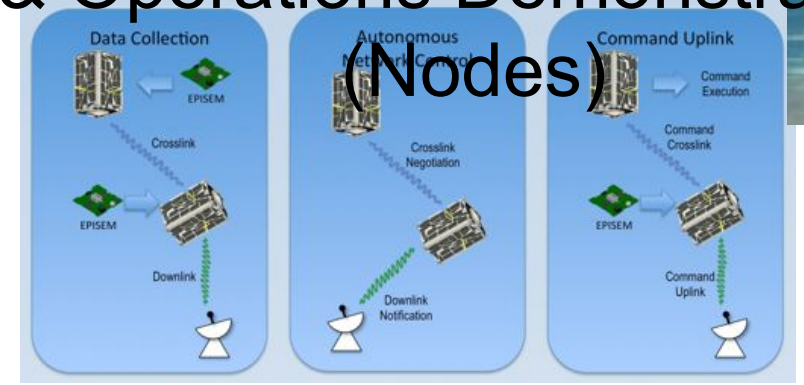


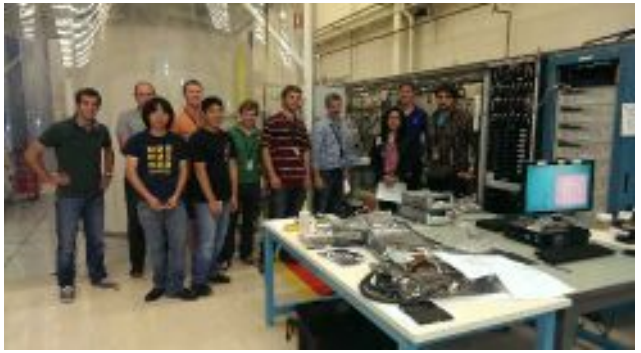


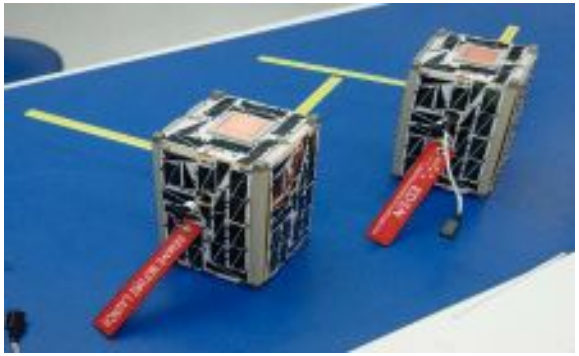
Super-Strypi
OCT 2015



Network & Operations Demonstration Satellite (Nodes)



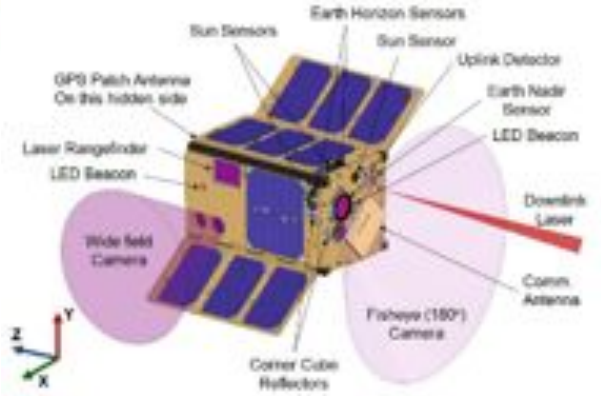


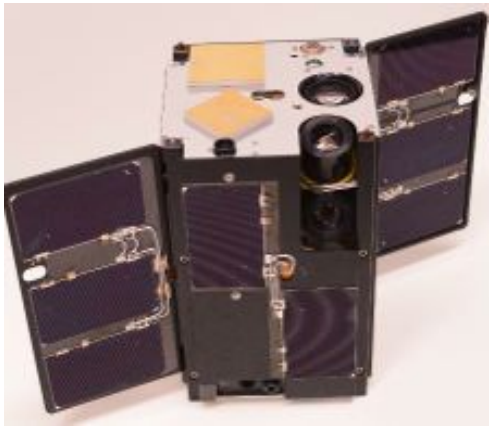


ISS CRS - Orbital 4

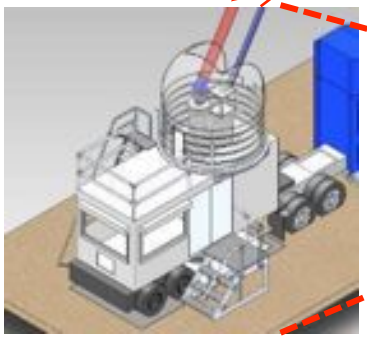
Optical C
Sensor D (OCSD)

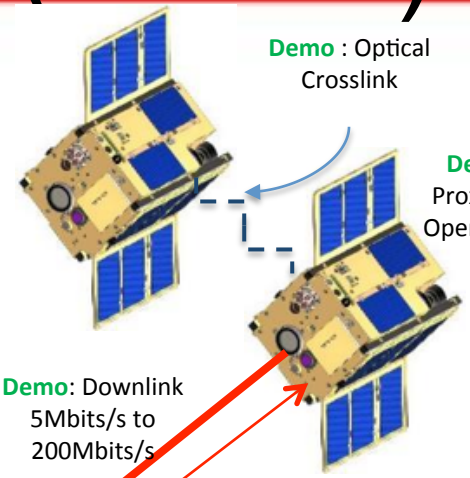
Falcon 9 – FormoSat-5 (NET DEC 2015)





Flight Unit #1





Demo : Optical Crosslink

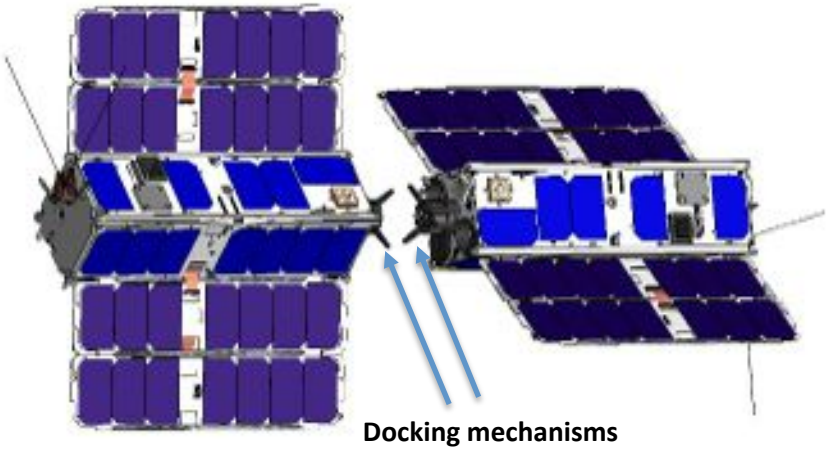
Demo: Proximity Operations

Demo: Downlink 5Mbits/s to 200Mbits/s

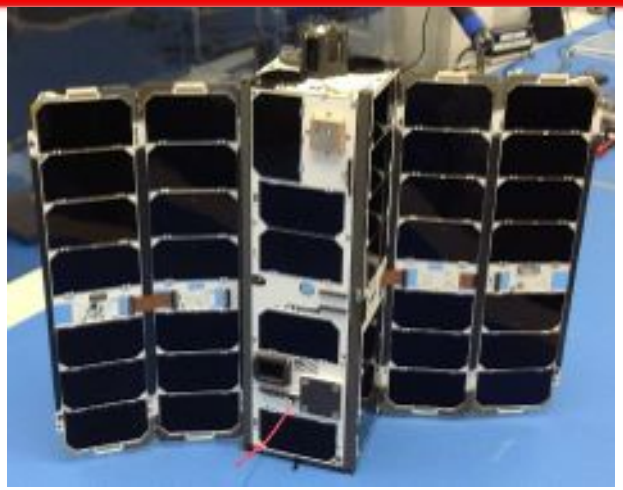
OCSD – 2 (1.5U)
(NRO-L55 - AUG 2015)

Demo: Uplink 10Kbits

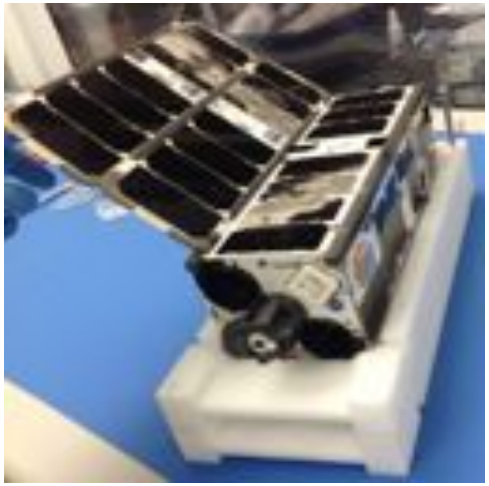
Cubesat Proximity Operations Demonstration



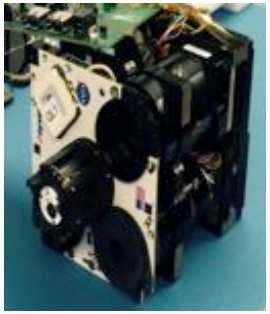
Docking mechanisms



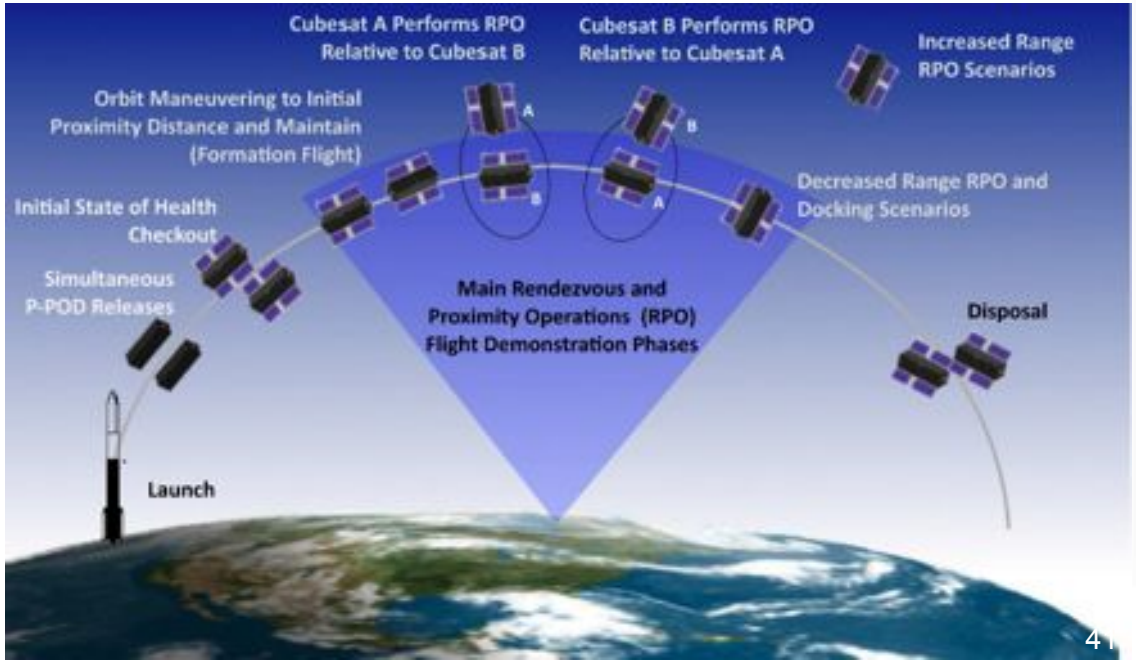
EDU Integration



EDU Integration

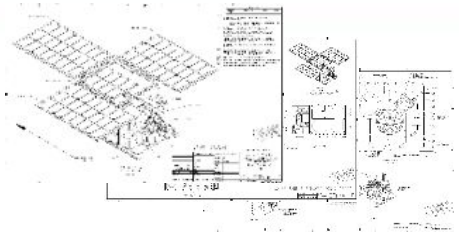


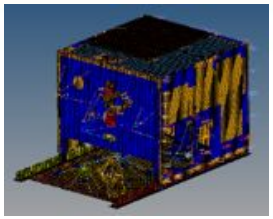
Rendezvous, Proximity Operations and Docking (RPOD) Module

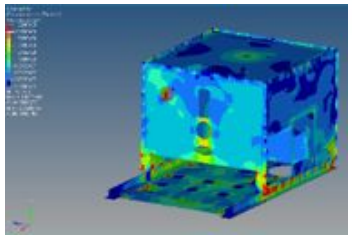


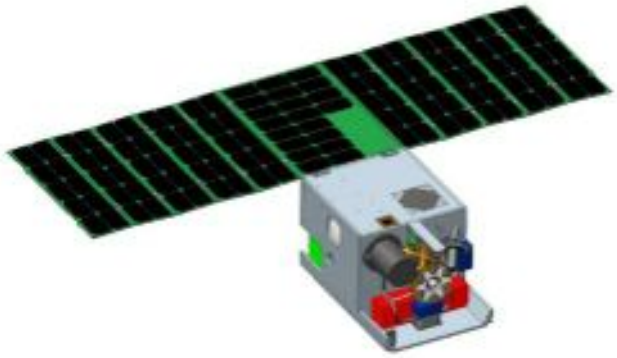
tyvak NANO-SATELLITE SYSTEMS INC.

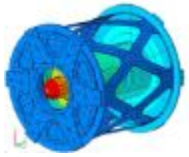
Iodine

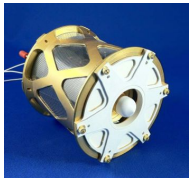


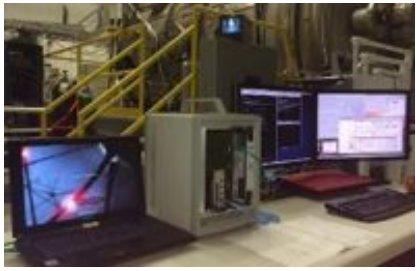


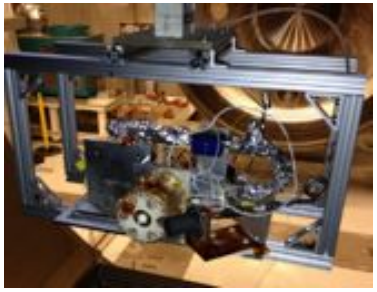












Propulsion Pathfinder

Spacecraft Specifications

- Mass: 10-12kg
- Quantity: One 6U CubeSat (multiple demonstrations)
- Orbit: 350-800 km, 98° or 51° incl.
- Size: 50 x 9.1 x 13.5 (*inches*)
- Communication: S-Band

Mission Description

The Propulsion Pathfinder Project objective is to perform multiple Earth orbit flight missions with Cubesat-scale spacecraft to demonstrate the operation of, and characterize the performance of, a variety of propulsion technologies suitable for small spacecraft mission applications including precise pointing, proximity operations, targeted deorbit, and small and large orbital maneuvers. The propulsion technologies to be demonstrated include but are not limited to at least one version of miniaturized electrospray propulsion and an RF Ion propulsion system.

LCCE - $30,102K

Status

The project was recently kicked off and is working towards MCR. Level 1 requirements are signed and Level 2 requirements are underway. System trades are being conducted and programmatics (cost estimates, schedule, and risk) are being defined. Procurement strategies are being defined for the candidate propulsion systems.

Critical Milestones

ATP	MCR	SRR/PDR	CDR	FHR	FRR/ORR	Launch	Mission Ops	Mission Duration	Project Closure
1/14/15									

Why Study Space Biology?

The limit of life in space, as we know it, is 12.5 days on a lunar round trip and 1 year in LEO. As we send people further into space, we have to use other

Beyond

36 million mi

Millions mi

240,000 mi

180-300 mi

62 mi

Distance

Unknown

Known

Extended ISS

Minutes

12.5 Days

6 Months

12 Months

3 Years

Mission Duration

- Overview
  - vision and projections
  - Where NASA is, and where it is going re smallsats existing programs
  - Highlight Technologies Tech Needs
  - DRM examples
  - Win-Win is leveraging
  - What WE can do to go forward TOGETHER
  - to meet OUR mutual challenges
  - for NASA comes first

Program Relevance, Goals, Objectives, & Customers

Relevance: *Contributes to 2 of 3 NASA Strategic Goals*

Goals and Objectives: *as related to NASA Strategic Goals*

NASA Strategic Goals	NASA Strategic Objectives	SST Program Goal: Promote the small spacecraft approach as a paradigm shift for NASA and the larger space community.	
Goal 1 – Expand frontiers of knowledge, capability, and opportunity in space By empowering the NASA community to...	**Objective 1.7** - Transform NASA missions and advance the nations capabilities by maturing crosscutting and innovative space technologies. Thereby supporting, Objective 1.1, 1.4, 15, and	1.) Identify and support the development and demonstration of new subsystem technologies to enhance the applicability of small spacecraft to perform future missions; **TRL 3 to 5**	2.) Use small spacecraft as platforms for affordably testing and demonstrating technologies and capabilities that might have more general applications in larger-scale spacecraft and systems; and **TRL 5 to 7**
Goal 2 - Advance understanding of Earth and develop technologies to improve the quality of life on our home planet By engaging our workforce and partners to...	Objective 2.3 – Optimize Agency technology investments, foster open innovation, and facilitate technology infusion, ensuring the greatest national benefit.	3.) Use small spacecraft as platforms for expanding the knowledge, experience and capabilities of individuals and teams within NASA, industry and academia to perform space missions.	4.) Support technology transfer from SSTP to SMD, HEOMD, academia, and industry.

Customers: *Future NASA missions in NASA Mission Directorates, other USA government agencies, academia, the aerospace industry.*


National Aeronautics and
Space Administration
Ames
Discovery Innovations Solutions
Actual photo of
TechEdSat-1 deployed
from ISS, Oct 4 2012

- Deorbit Requirements
- DRM
  - Planetary Defense
    - Asteroid Detection, Characterization and Impact Mitigation
    - Sample Return
    - NEA Observation
- Improved Deep Space Networks for communications and GNC