NASA and Small Satellite Research

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Mission Design Division

NASA-Ames Research Center

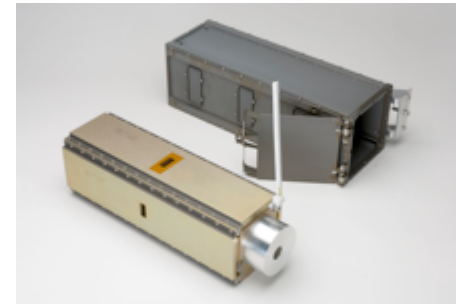
- NASA's Interest in Small Satellites
- Nanosatellite Background
- HQ Programs & Investments
- Future Missions & Opportunities
- Enabling Technologies Needed

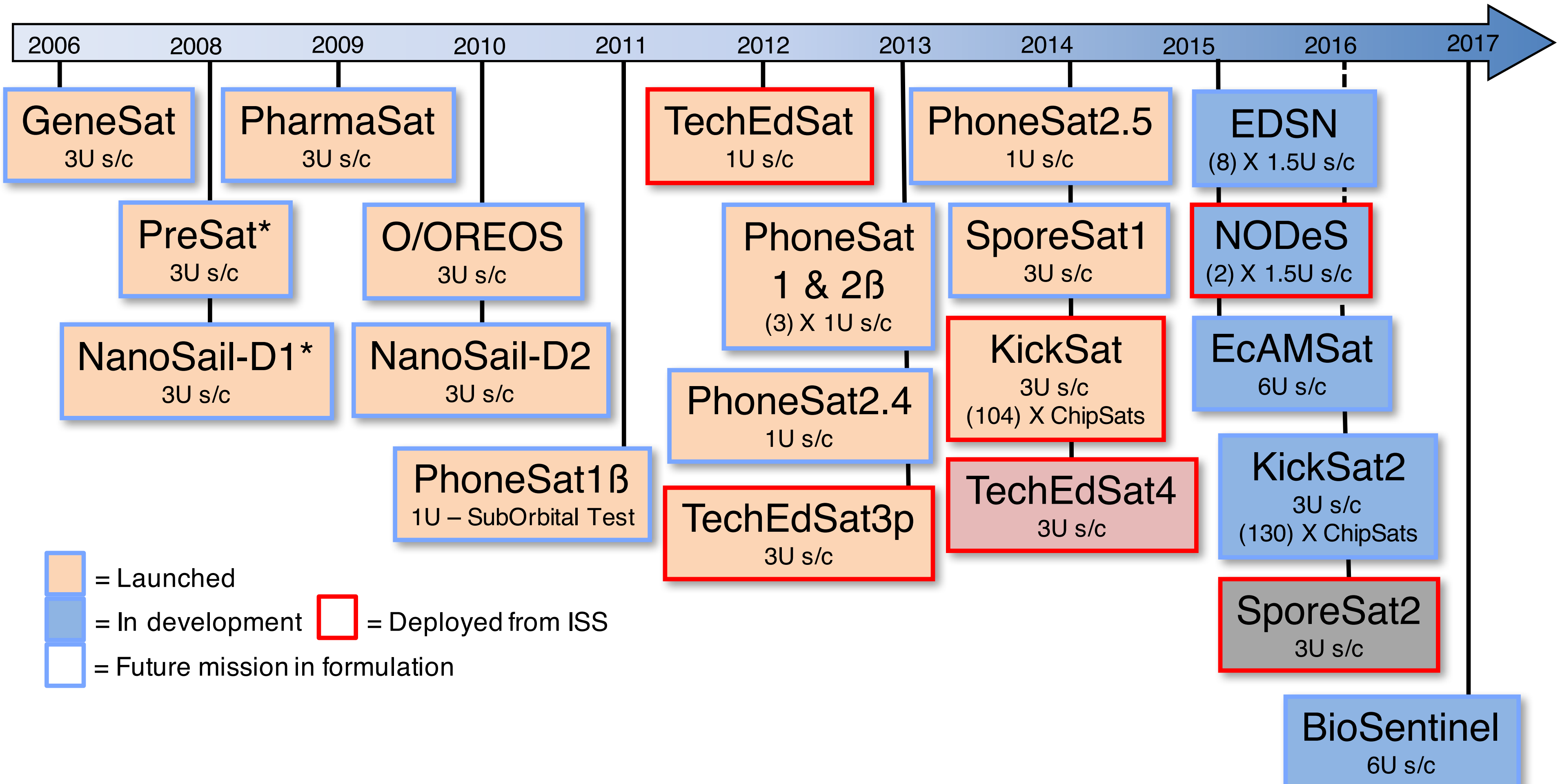
CubeSat 2015

Cal Poly San Luis Obispo

22 Apr 2015

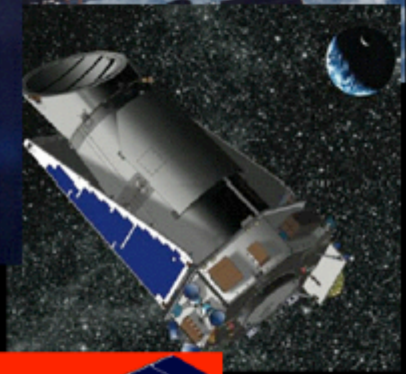
Introduction



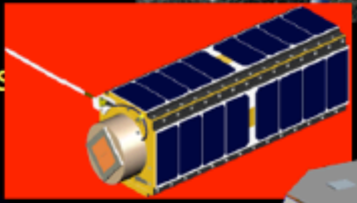


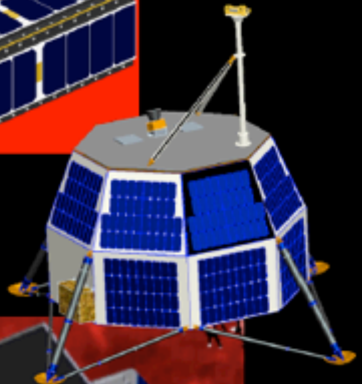
Spacecraft Mission Sizing

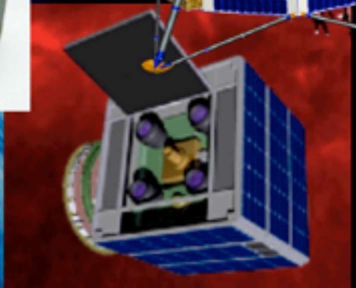
- Larger Spacecraft Excel at:
  - Large Diameter Sensors, Optics, Antennas, Detectors
  - Large Scale Investigations, Several Instruments
  - Lower calculated risk per individual mission
  - Lower cost per kilogram
  - Utilize "Proven Launchers"



- 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!

Relevance of Small Spacecraft to NASA Strategic Goals

SSTP 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.*

CUBESAT MISSIONS & TECHNOLOGY DEVELOPMENT PROGRAMS

NASA HQ PROGRAM SUPPORT

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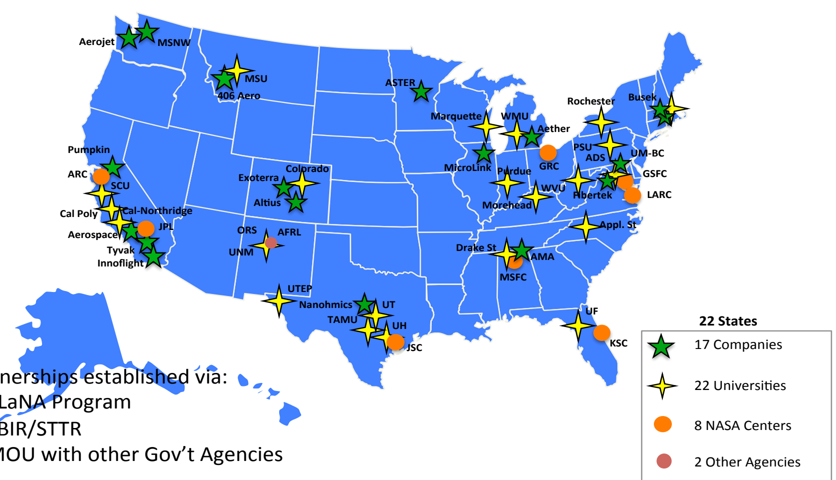
Small Spacecraft Technology Nationwide Participants and Partners

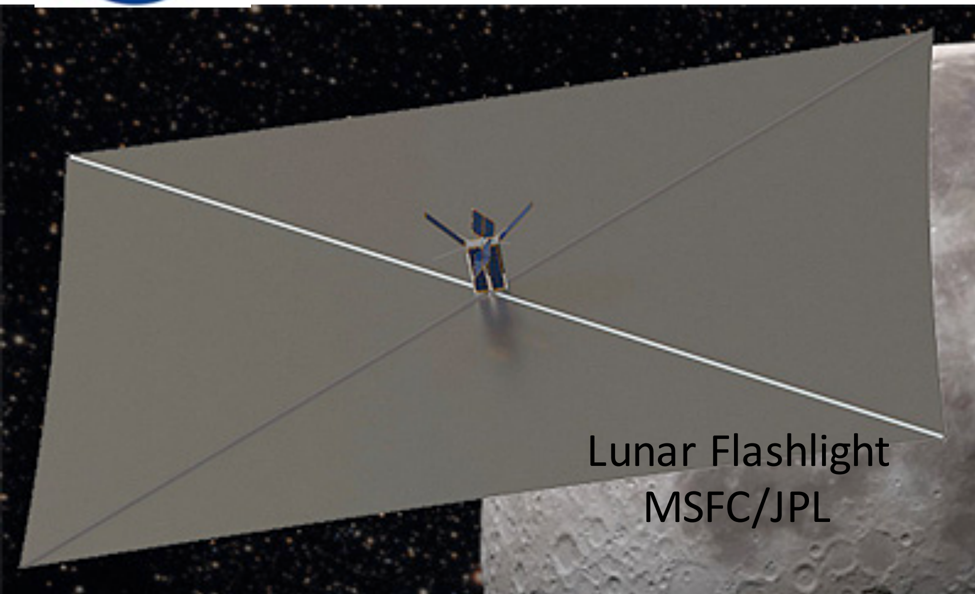


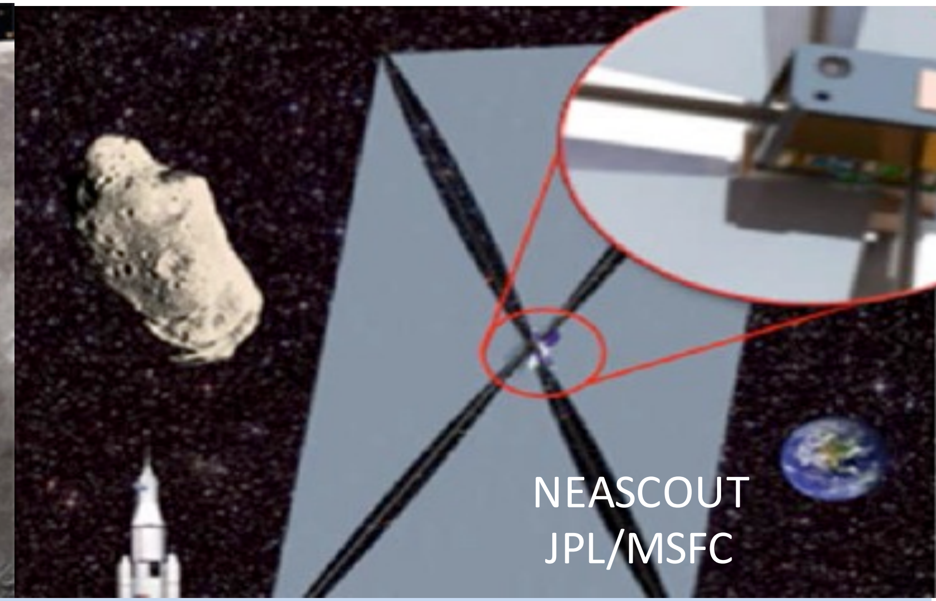
Partnerships established via:

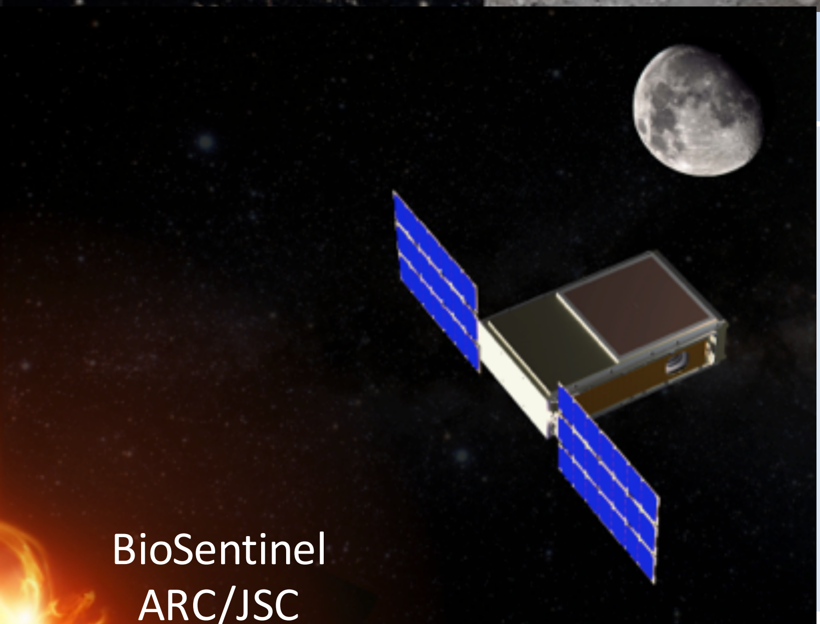
- ELaNA Program
- SBIR/STTR
- MOU with other Gov't Agencies

www.nasa.gov/smallsats

DEEP SPACE NANOSATELLITE MISSIONS





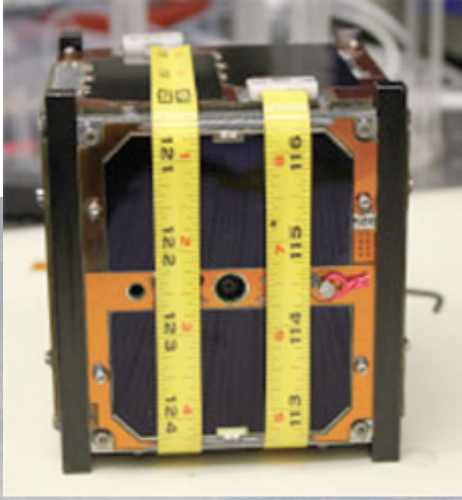


SLS EM-1 Opportunity LRD 2018

HEOMD/AES funded missions.

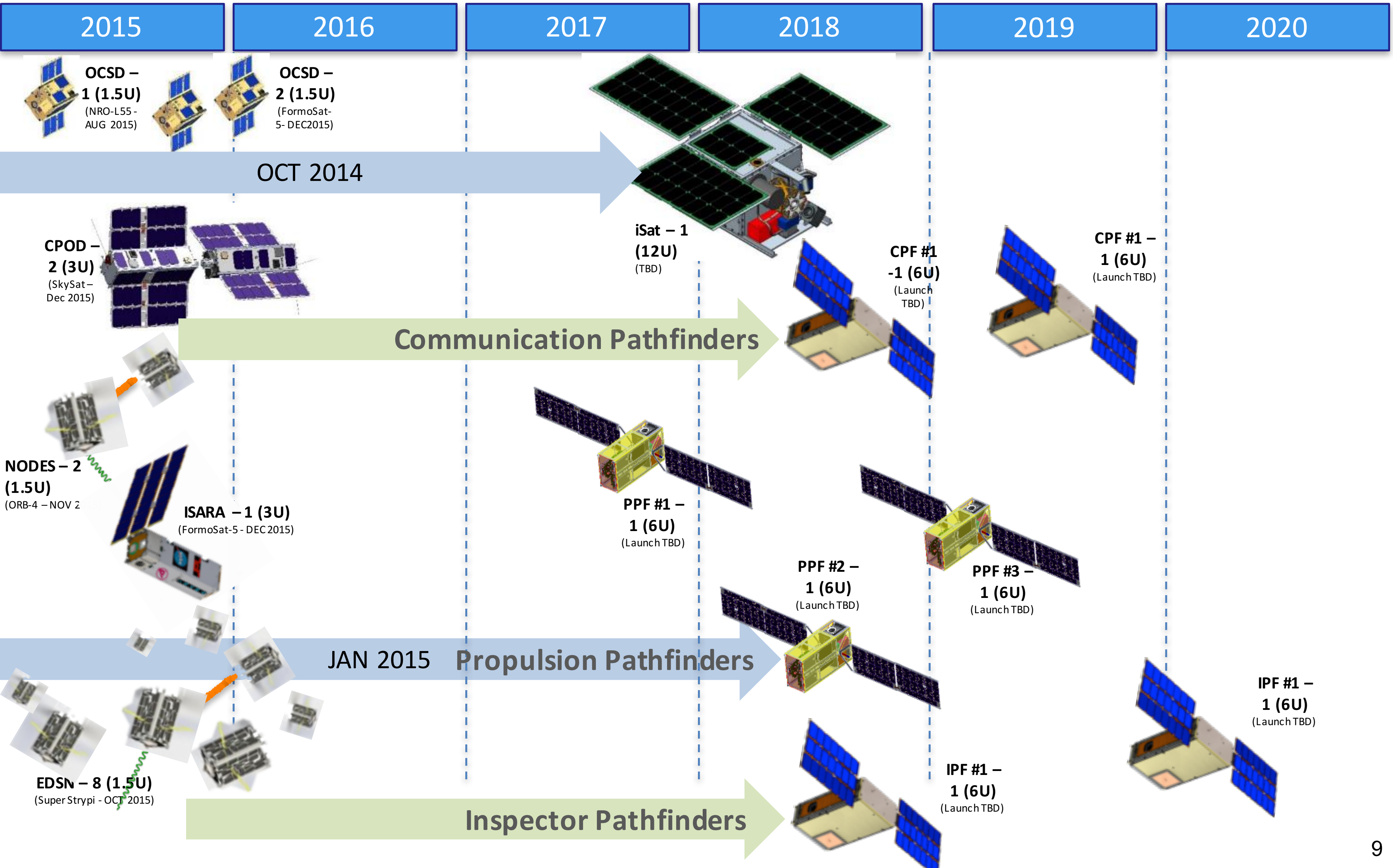
- Lunar Flashlight – Locate ice deposits in the Moon's permanently shadowed craters.
- NEA Scout – Flyby/Rendevous and characterization of one NEA that is a candidate for a human mission.
- BioSentinel- Study Radiation Induced DNA of live organisms in cis-lunar space.

SMD ROSES Projects



- **Helio-1 "ELFIN-STAR"**
  - 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
  - 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
  - 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.

STMD SSTP MISSIONS



SUPPORT FOR LAUNCH & MISSION OPPORTUNITIES

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

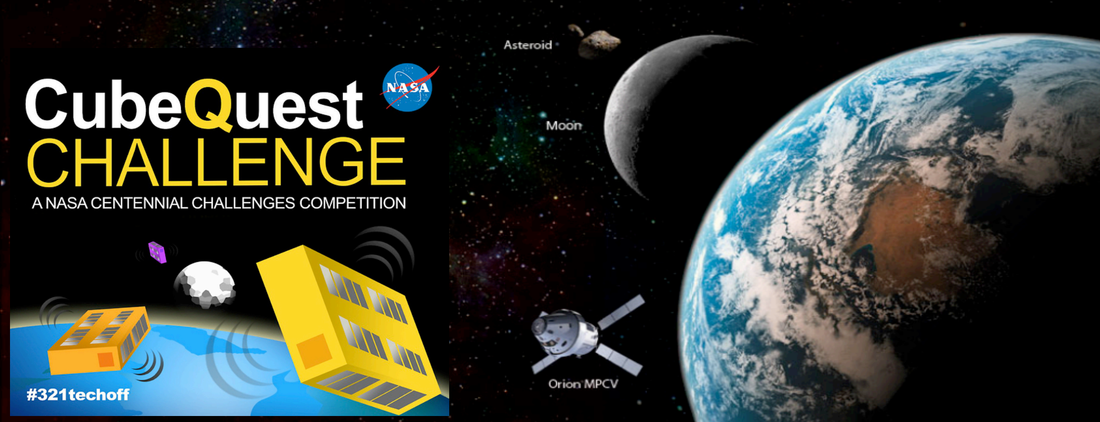
As part of the White House Maker Initiative, NASA is seeking to leverage the growing community of space-enthusiasts to create a nation that contributes to NASA's space exploration goals.

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

These Missions provide an opportunity to boost Cubesats to deep space and enagle science, technology demonstration, exploration or commercial applications in that environment.

HEOMD/AES NextSTEP Broad Agency Announcement.

SMD – Small Innovative Missions for Planetary Exploration (SIMPLEX)



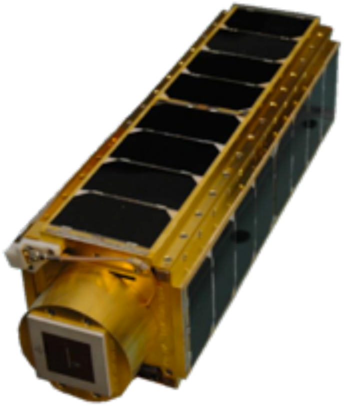
SBIR/STTR SMALL SAT TECHNOLOGIES

Program	Year	Subtopic	Lead Center	Participating Centers
SBIR	2015	S3.02 Propulsion Systems for Robotic Science Missions	GRC	JPL, MSFC
SBIR	2015	S3.05 Guidance, Navigation and Control	GSFC	ARC, JPL, JSC
SBIR	2015	S3.07 Thermal Control Systems	GSFC	ARC, GRC, JPL, JSC, LaRC, MSFC
SBIR	2015	Z4.01 Small Spacecraft in Deep Space: Power, Navigation, and Structures	ARC	
STTR	2015	T5.01 Autonomous Communications Systems	GRC	GSFC
Select	2015	S20.01 Novel Spectroscopy Technology and Instrumentation	GSFC	JPL

FUTURE MISSION and TECHNOLOGY CONCEPTS

Space Biology Nanosats: *Testing Life in Space*

Validating and Enhancing ISS biological testing



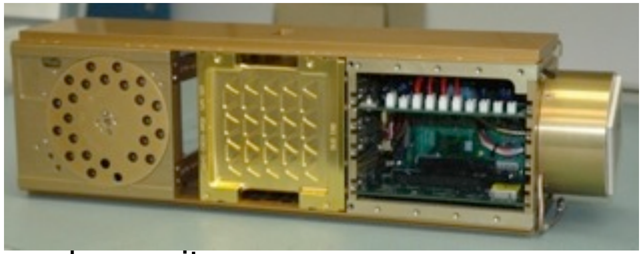
PharmaSat

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

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

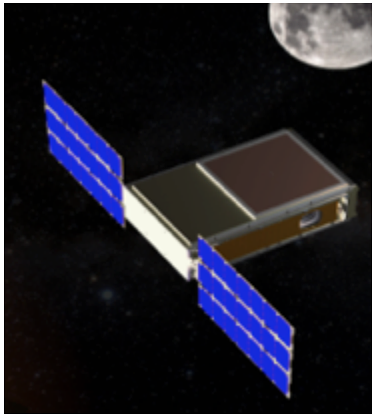
SporeSat 1 & SporeSat 2 (ISS deployed)



- 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 μgravity



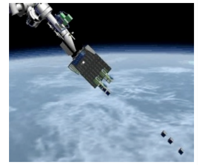
BioSentinel

- 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.

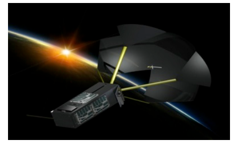
TechEdSats: *Re-Entry Technology Demonstrators*

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

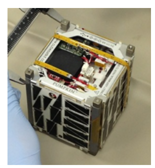


TechEdSat-3p: First 3U Nanosat from ISS
- 3U Nanosat, Launched August 4 2013 (HTV-4), ISS deployed on Nov 19, 2013
- First sub-scale Exo-Brake test; Iridium downlink/uplink test; Deployment validation burned up during Earth Re-entry



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

TechEdSat-5: Deploying from ISS 2016



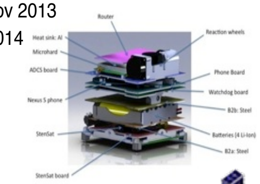
PhoneSats/EDSNs: *COTS Tech Demonstrators*

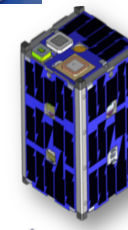
(Consumer-grade technology evaluation/validation for NASA use)

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

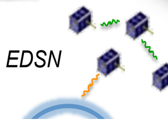
PhoneSat(s) 2ß, 2.4, and 2.5
- 1U Cubesats, avionics derived from Nexus S Phone
- PhoneSat 2ß Launched April 21, 2013 on Antares-1
- PhoneSat 2.4 launched on a Minotaur 1 – ELaNa 4 in Nov 2013
- PhoneSat 2.5 launched on SpaceX – ELaNa 5 in April 2014



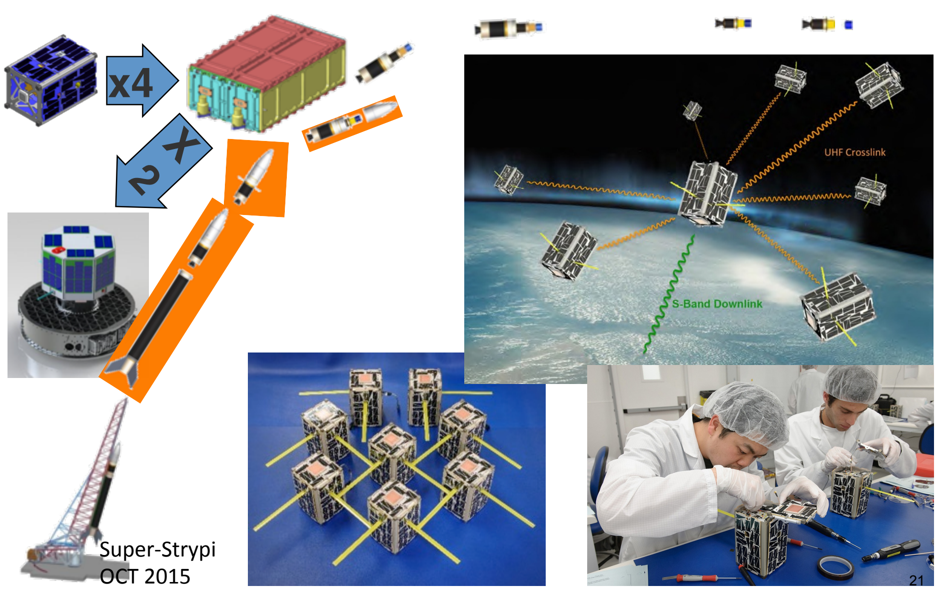


EDSN: First Nanosat Swarm
- Phonesat as core of 8 x 1.5U Cubesats,
- EDSN Swarm satellites using PhoneSat 2 components

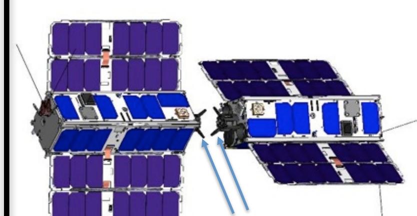
NODeS: ISS Nanosat Swarm demonstrator
- 2 EDSN Nanosats with Advanced Software deploying off of ISS



EDSN

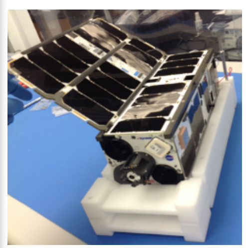


CPOD

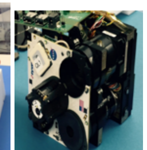


Docking mechanisms

EDU Integration

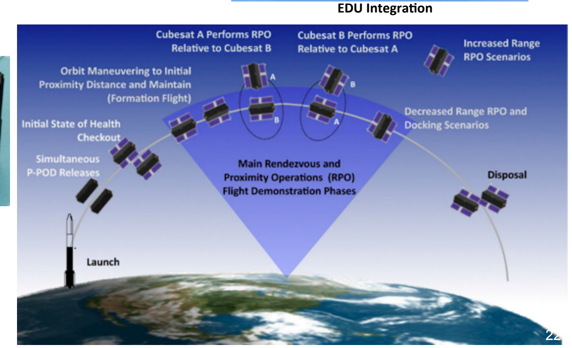


EDU Integration

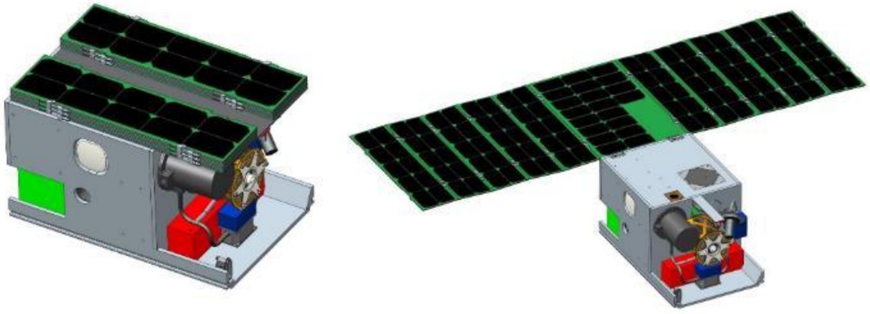


Rendezvous, Proximity Operations and Docking (RPOD) Module

tyvak

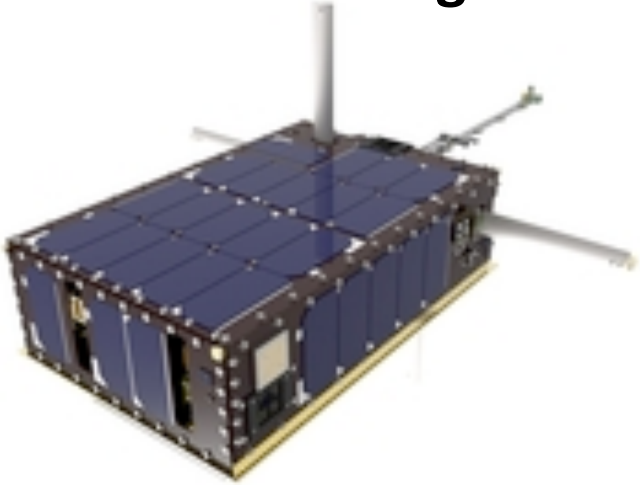


iSAT 12U Propulsion Pathfinder MSFC



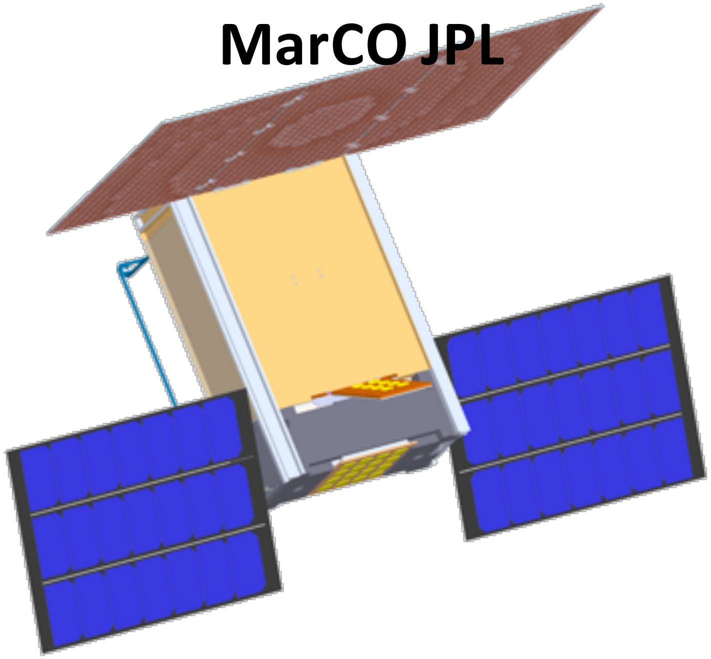
iodine Hall technology

GSFC Delingr 6U



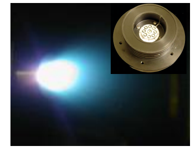
LaRC Autonomy Incubator

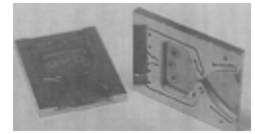
MarCO JPL



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

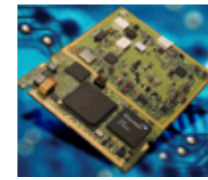

NanoThrusters


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

<u>Enabling Science Missions:</u>

Precision Formation Flying

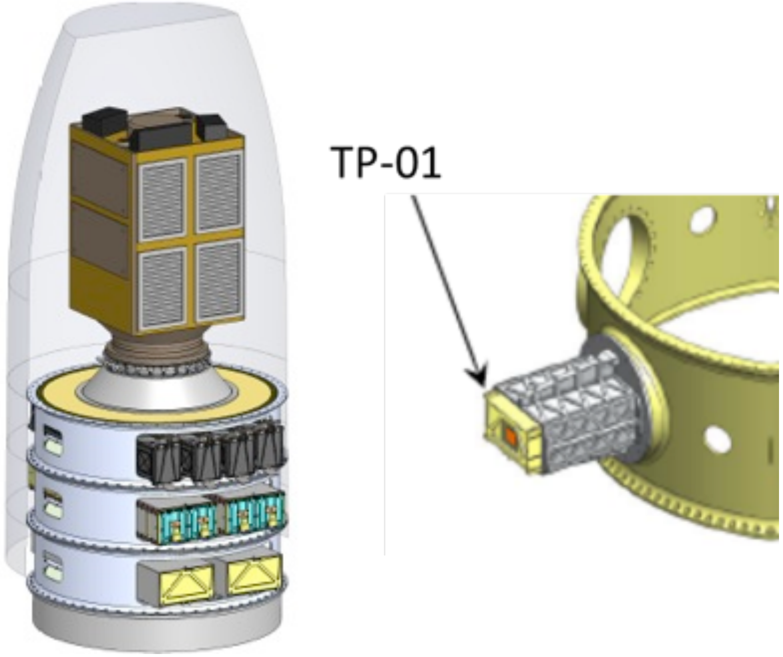
Remote Imaging: Earth/Lunar Science

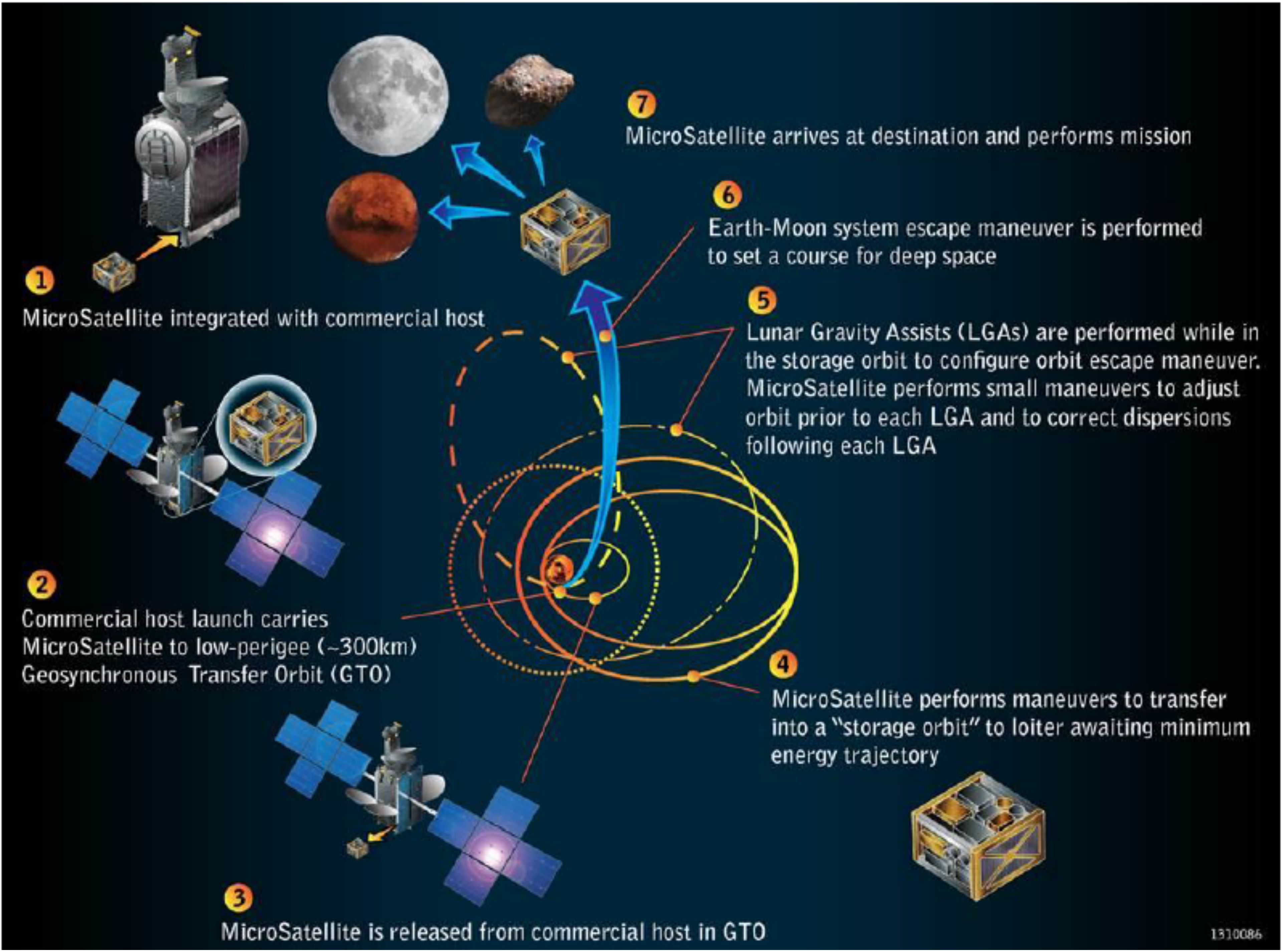
Autonomous Satellite Maintenance

Space Physics & Astrophysics

Exploration: Lunar, NEOs, Comets

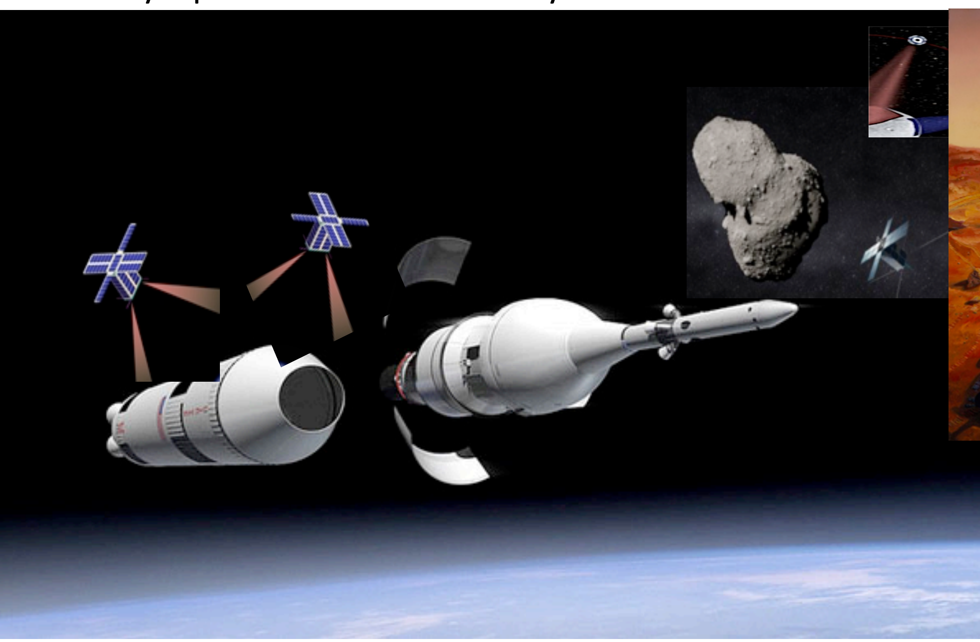
ACCESS TO SPACE



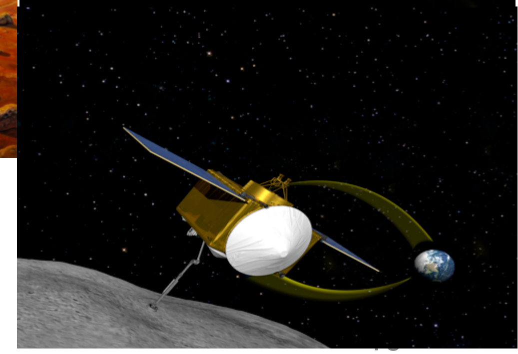


1
MicroSatellite integrated with commercial host
2
Commercial host launch carries MicroSatellite to low-perigee (~300km) Geosynchronous Transfer Orbit (GTO)
3
MicroSatellite is released from commercial host in GTO
4
MicroSatellite performs maneuvers to transfer into a "storage orbit" to loiter awaiting minimum energy trajectory
5
Lunar Gravity Assists (LGAs) are performed while in the storage orbit to configure orbit escape maneuver. MicroSatellite performs small maneuvers to adjust orbit prior to each LGA and to correct dispersions following each LGA
6
Earth-Moon system escape maneuver is performed to set a course for deep space
7
MicroSatellite arrives at destination and performs mission
1310086

Cubesat Applications

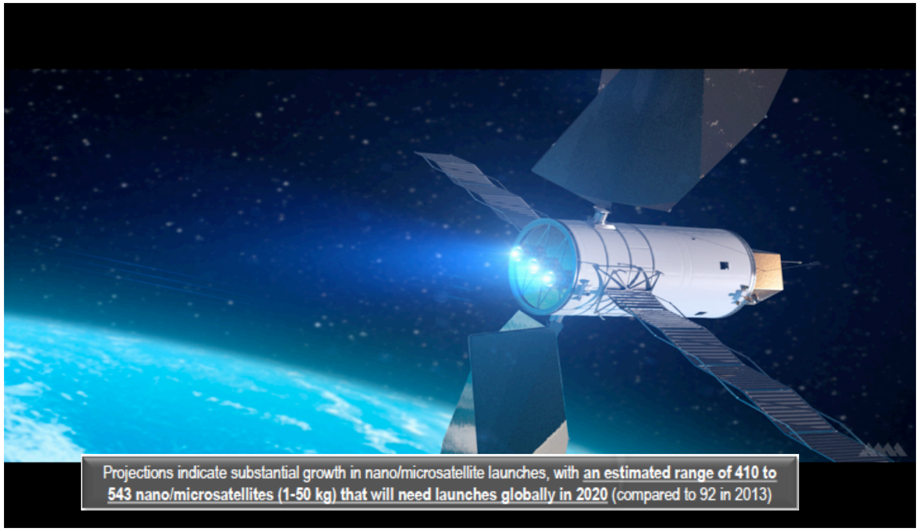


SAMPLE RETURN &
EDL TECHNOLOGIES

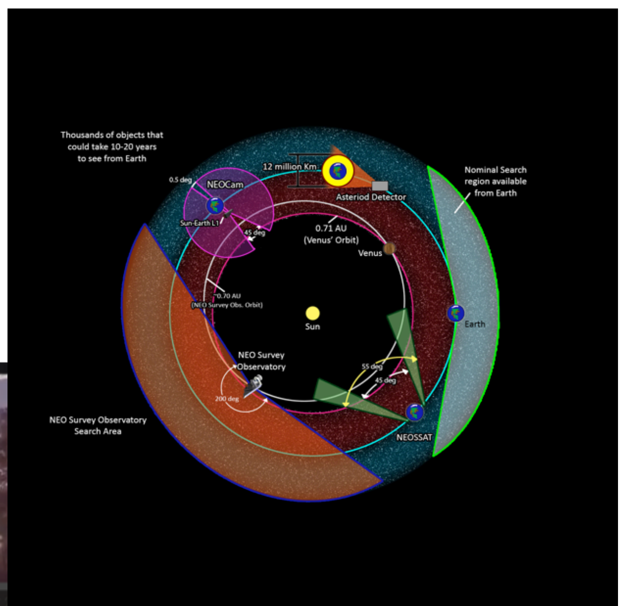


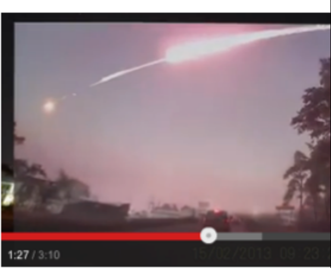
Cubesat Missions and Technologies

ENABLING FUTURE MISSIONS & EXPANDING TECHNOLOGY PORTFOLIO



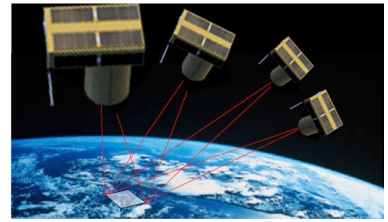
Planetary Defense
Asteroid Detection
Investigation & Impact Mitigation



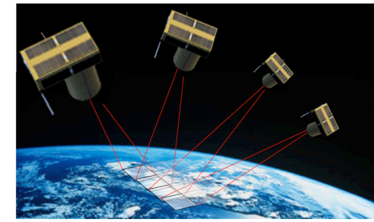


Earth Science Observations

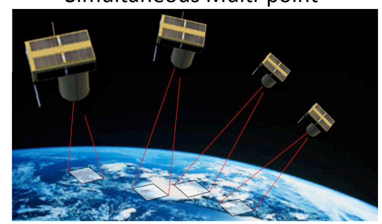
Super Resolution



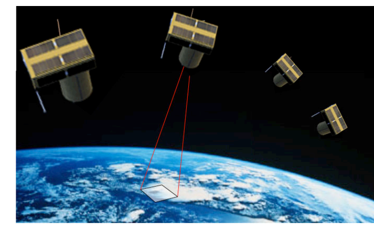
Mosaic

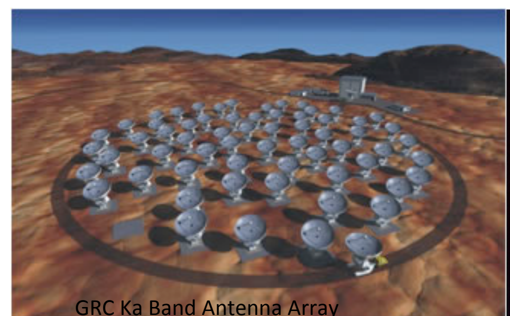


Simultaneous Multi-point



Multi-task

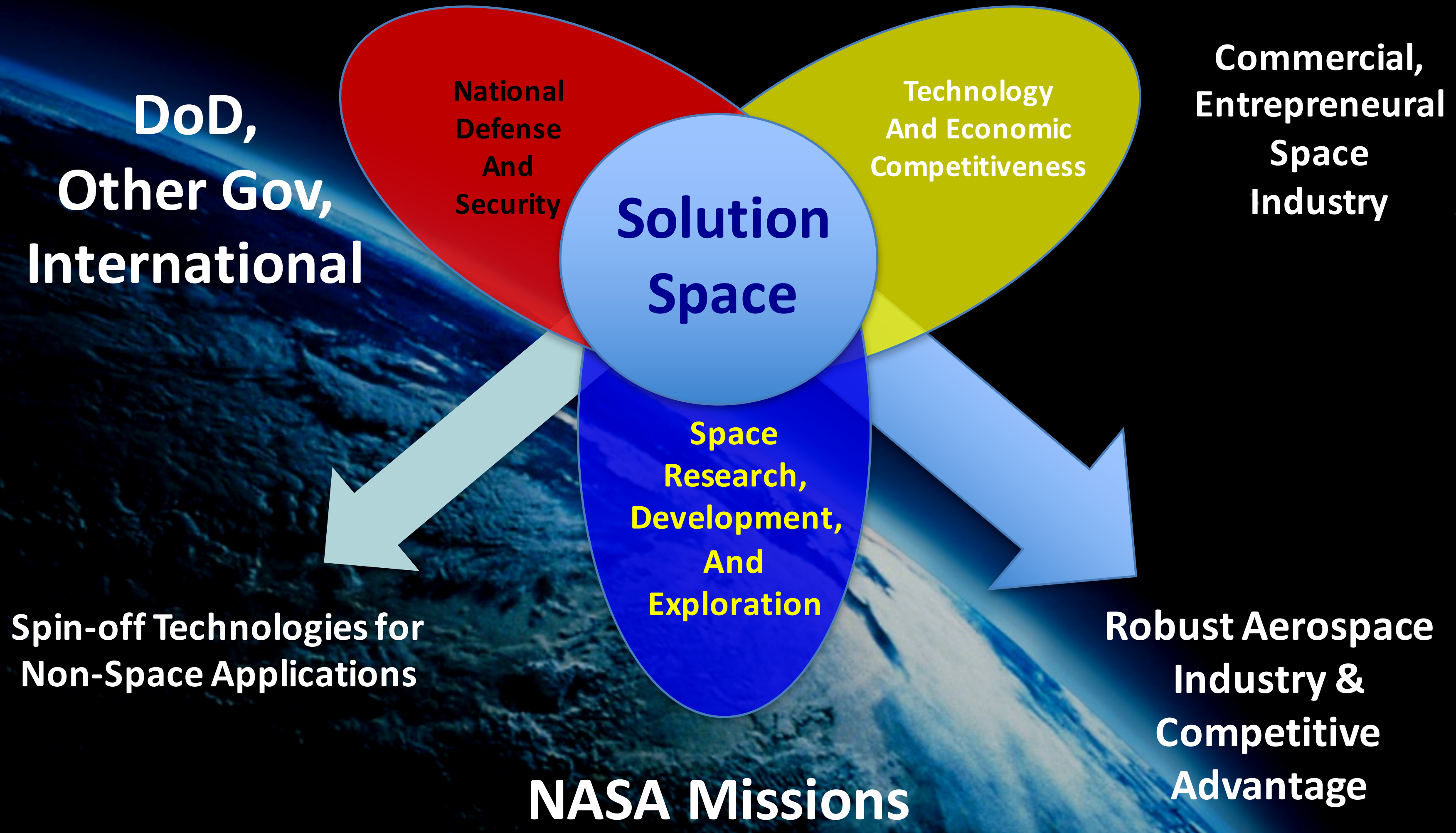




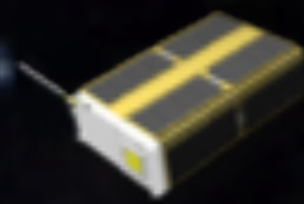
Enhanced Communication and Tracking Stations to support Multiple missions.

Technology and Innovation Strategy

... *Addressing Global Needs*



NASA



NASA Engages with Emerging Space:
Forging the New Space Economy

Humans have been traveling into space for more than half a century. Prior to that first flight, however, American citizens had been thinking about and working towards spaceflight for over a hundred years. The story of the continuing American journey in space has been an epic one, and NASA is proud to have been one of the central characters of that story. Over the decades NASA's role has been to steadily build humanity's capability to function away from our home planet on behalf of the American public. The Mercury Program showed us that we could go into space and return safely, the Gemini Program taught us essential lessons in operating in space, and the Apollo Program demonstrated that our drive to explore could bring about the once unimaginable feat of a human on the Moon. From there, the Space Shuttle taught us how to return to space on a continuous basis, and with the International Space Station (ISS), we have finally achieved a permanent home in space.

Today, the rising arc of NASA's story includes the development of new rockets and spaceships—such as the Space Launch System and the Orion multipurpose crew vehicle—that will enable us to go beyond the Earth's environs, to operate in the vicinity of the Moon, and eventually to move out further into the solar system.

NASA Engages with Emerging Space:
Advancing Space Technology

Extraordinary endeavors, like moving asteroids or supporting people on voyages to Mars, require extraordinary technologies. NASA's community of innovators includes the NASA workforce, small businesses, and established and emerging space companies. This is a community that regularly develops, tests, and implements cutting-edge research, and which yields potentially transformative solutions that can accelerate timelines, slash costs, or multiply science return. NASA makes progress in essential space technologies daily, enabling more capable and far-reaching future space activities for our nation.

NASA's Space Technology portfolio includes critical technologies for expanding American activities in the solar system as well as technologies that will benefit the public and our economy

Solar Electric Propulsion

Using advanced Solar Electric Propulsion (SEP) technologies is an essential part of future missions into deep space with larger payloads. NASA's SEP Project will develop and mature technologies for its asteroid redirect mission and ultimately human and robotic exploration of Mars and beyond. SEP systems can reduce the mass of a satellite, which could offer significant cost savings for government and commercial satellites. Solar electric propulsion enables the efficient transport of heavy payloads from low Earth orbit to higher orbits. It could significantly benefit the U.S. satellite industry, and already a number of U.S. satellite manufacturers have developed or are developing solar electric satellite buses. Commercial missions could use solar electric propulsion tugs to place, service, resupply, reposition and salvage space assets.

Cryogenic Propellant Storage and Transfer

Cryogenic Propellant Storage and Transfer will allow a new generation of spacecraft to operate deeper and longer in space because the spacecraft will be able to refuel along the way. Cryogenic propellants provide high-energy propulsion solutions critical to future, long-term human exploration missions beyond LEO. NASA is currently developing the Cryogenic Propellant Storage and Transfer Project to explore a means of storing and transferring these propellants in space for long durations, and preventing temperature fluctuations that contribute to fuel losses due to boil-off. The technologies may lead to the development of propellant depots—space gas stations—that will be important as traffic volumes in the solar system increase.

Laser Communications

Laser communication between space assets can provide 10 to 100 times higher data rates than radio, and enable communication across tens of millions of kilometers. NASA recently successfully tested laser communications on its LADEE lunar mission. NASA has developed the hardware and documentation to also transfer this technology over to commercial developers. This capability could revolutionize the way data is transmitted and received, dramatically improving communications between satellites, probes, and spacecraft deployed throughout the solar system.

Early Stage Innovations

NASA's early stage space innovations address high priority technical needs that America's space program must master to enable future missions. This program reaches out to American innovators through NASA's Innovative Advanced Concepts (NIAC) program, which encourages potentially transformative engineering concepts that could enable entirely new missions or breakthroughs in future aerospace capabilities. It involves universities, through its Space Technology Research Fellowships, to select technology research that is a dramatic improvement over existing capabilities. NASA has over 450 activities in early stage innovation, and is working to include more of America's top universities to address NASA's technical needs.

Flight Opportunities Program

The Flight Opportunities Program provides opportunities to test and demonstrate spacecraft technologies and payloads that could help revolutionize future space missions. In June 2013, NASA announced it is also considering funding flights of astronaut researchers aboard some vehicles as opportunities present themselves. Seven companies are providing flight opportunities for payloads.

Small Satellite Programs

NASA is pursuing development of new subsystem technologies to enhance or expand the capabilities of small spacecraft; support flight demonstrations of new technologies, capabilities and applications for small spacecraft; and use small spacecraft as platforms for testing and demonstrating technologies and capabilities that might have more general applications in larger-scale spacecraft and systems. A recent example is NASA's Fast, Affordable, Science and Technology Satellite (FASTSAT) mission, which successfully demonstrated a capability to build, deploy and operate a science and technology flight mission at lower costs than previously possible.