NASA AMES 70 YEARS OF INNOVATION Platinum Jubilee

National Aeronautics and Space Administration

Research and Technology Implications and Applications for Very Small (MesoScale) Spacecraft

{THE INCREASING IMPORTANCE OF NANOSATS FOR SCIENCE, TECHNOLOGY, MICROGRAVITY AND BIOLOGY}

6U CubeSat low cost space missions workshop
17 & 18 July 2012
AITC, Mt Stromlo Observatory, Canberra Australia

John W. Hines
Chief Technologist
NASA-Ames Research Center
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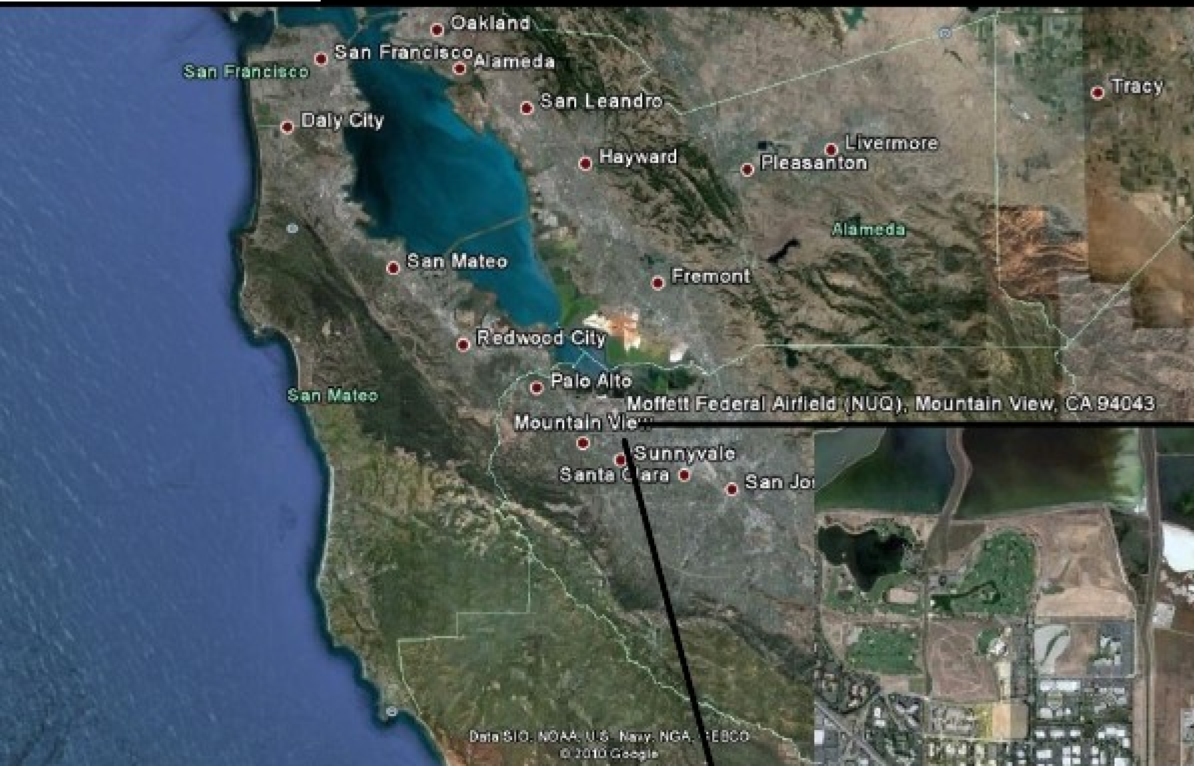
650-604-5538

17 July 2012

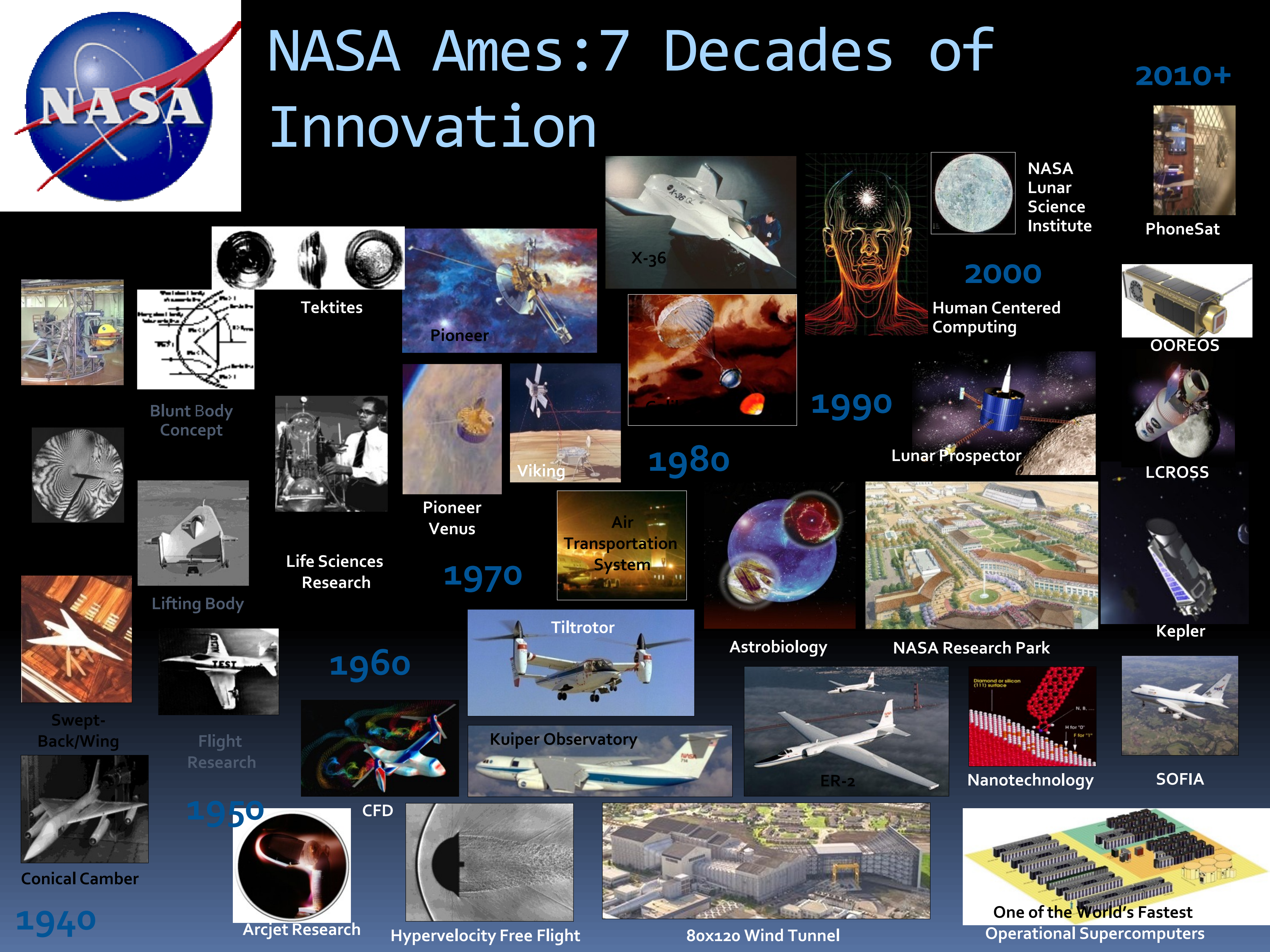
Ames Research Center
in Silicon Valley...
...Innovation starts here

NASA-Ames Research Center



San Francisco Bay
Area
CA, USA

Ames Research Center
in Silicon Valley...
...Innovation starts here


NASA
NASA Ames:7 Decades of Innovation
2010+
PhoneSat
NASA Lunar Science Institute
X-36
2000
Human Centered Computing
OOREOS
Tektites
Pioneer
Blunt Body Concept
1990
Lunar Prospector
LCROSS
Viking
1980
Pioneer Venus
Life Sciences Research
Air Transportation System
1970
Lifting Body
Kepler
Astrobiology
NASA Research Park
Tiltrotor
1960
Swept-Back/Wing
Flight Research
Kuiper Observatory
ER-2
Nanotechnology
SOFIA
CFD
1950
Conical Camber
Arcjet Research
Hypervelocity Free Flight
80x120 Wind Tunnel
One of the World's Fastest Operational Supercomputers
1940

ARC CORE COMPETENCIES

- Entry, Decent and Landing Systems
- Advanced Computing and
- Intelligent/Adaptive Human & Robotic Systems
- Air Traffic Management
- ARC
- Aerosciences
- Astrobiology
- Space, Earth and Life Sciences
- End-to-End Low Cost Aerospace Missions

http://www.nasa.gov/offices/oct/home/index.html

www.nasa.gov

NASA SPACE TECHNOLOGY ROADMAP
TECHNICAL AREA BREAKDOWN STRUCTURE

OCT - Complete Technology Maturation Pipeline

- Space Technology Research Grants

- NASA Innovative Advanced Concepts (NIAC)

- Center Innovation Fund

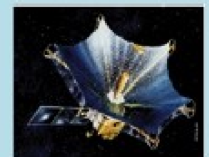
- Centennial Challenges Prize

- Small Business Innovation Research & Small Business Technology Transfer (SBIR/STTR)

- Game Changing Development

- Franklin Small Satellite Subsystem Technologies

- Flight Opportunities



- Technology Demonstration Missions

- Edison Small Satellite Demonstration Missions

SSTP

National Aeronautics and Space Administration

Small Spacecraft Technology Program

Office of the Chief Technologist

Technology Development

Develop subsystem technologies that will result in transformational capabilities for small spacecraft.

"Push" technologies/capabilities considered for TRL advancement from 3/4 to 5/6 may include:

- formation flying
- long life power systems
- precision pointing
- deployable apertures
- autonomous swarm operations
- miniaturized payload instrumentation
- multifunctional systems
- plug-and-play systems
- advanced thermal management systems
- heat- and radiation-tolerant electronics
- propellant-less or highly efficient propulsion
- other technology enablers
- proximity operations
- robotics
- space-to-space power transmission
- other system interoperability
- electro-optics imaging & sensing

Program Investment Strategy:

- solicit technology development projects
- solicit technology flight demonstration projects
- direct technology and flight projects
- small spacecraft infrastructure and standards

nasa.gov/offices/oct
www.NASA.gov

Technology Demonstration

Develop and operate a series of NASA-focused small spacecraft demonstration missions.

Competitively selected missions are expected to provide technology focused demonstrations such as:

- formation flying
- payload recovery
- orbital debris removal
- autonomous/collaborative/close proximity operations
- advanced power systems (long life or space-to-space transmission)
- advanced propulsion
- miniaturized remote sensors
- deployable apertures
- autonomous swarm
- robotics
- interoperable systems

Points of Contact

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Small Spacecraft at Ames:

Where We are Going

- Trend is for Smaller Technology
- Concurrent applications
- Solid R&D Foundations
- Well-Informed Make or Buy Decisions
- Constrained Budgets
- International Collaborative Focus
- Next Generation Workforce Training

ARC Small Spacecraft and Missions Enterprise ….

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 orbiter
  - 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!

Kepler Spacecraft

http://www.nasa.gov/mission_pages/kepler/

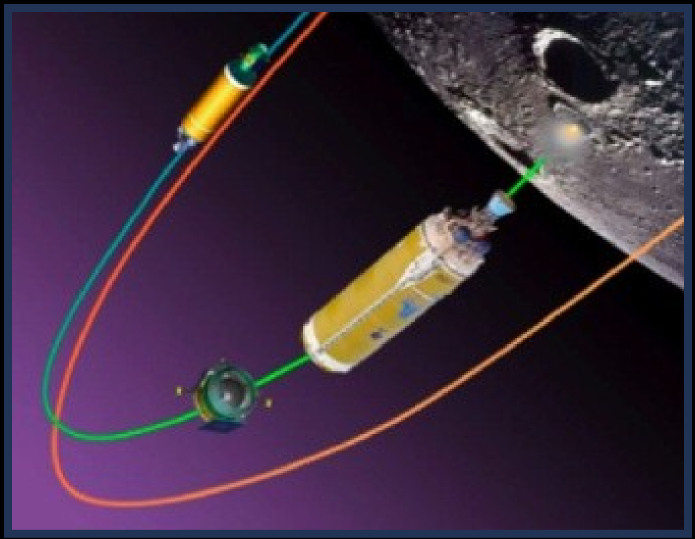
Kepler is a space observatory launched by NASA to discover Earth-like planets orbiting other stars. The spacecraft, named in honor of the 17th-century German astronomer Johannes Kepler,

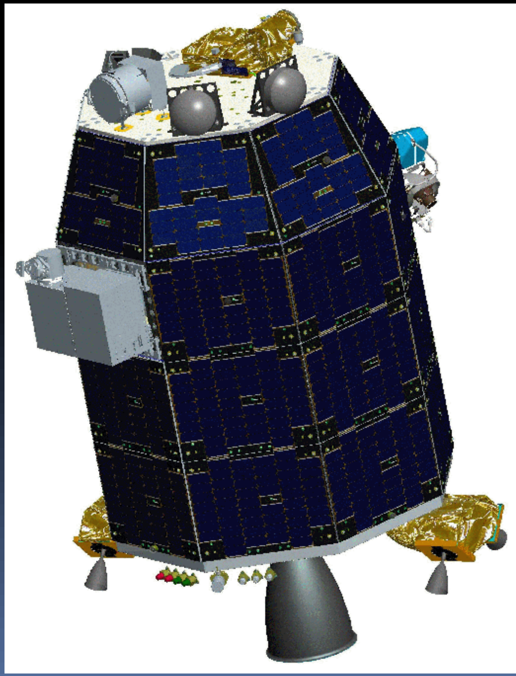
Launch date: March 7, 2009 3:49 AM Orbit height: 92,955,807 miles (149,597,871 km)
Speed on orbit: 3.661 miles/s (5.892 km/s)
Cost: US$ 550 million
Launch site: Cape Canaveral Air Force Station Launch Complex 17
Manufacturer: Ball Aerospace

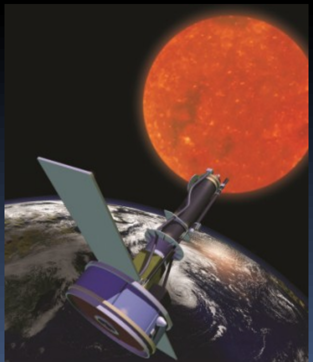
Kepler Planet Count
Confirmed Planets: 74
Planet Candidates: 2,321
Eclipsing Binary Stars: 2,165

Photometer |
The Kepler photometer is basically a Schmidt telescope design with a 0.95-meter aperture and a 105 square deg (about 12 degree diameter) field-of-view (FOV). It is pointed at and records data from just a single group of stars for the three and one-half or more year duration of the mission. The photometer is composed of just one "instrument," which is, an array of 42 CCDs (charge coupled devices). Each 50x25 mm CCD has 2200x1024 pixels.

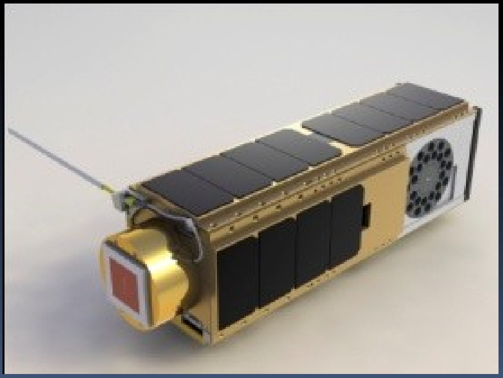
Innovation in Small Satellites





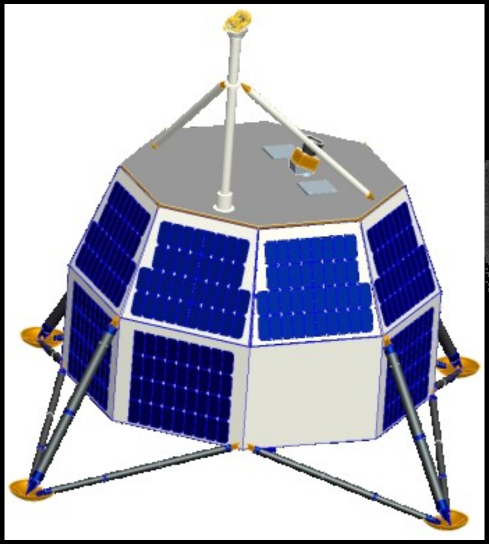


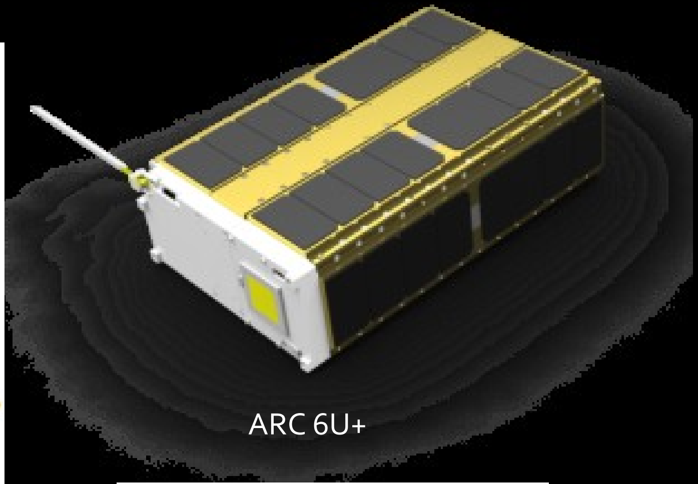
IRIS



O/OREOS

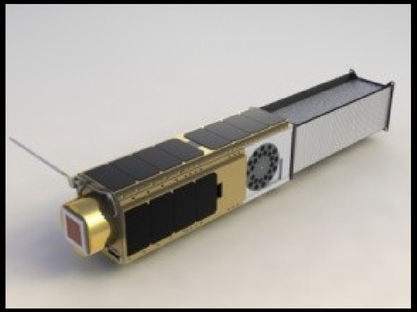
Platform Versatility

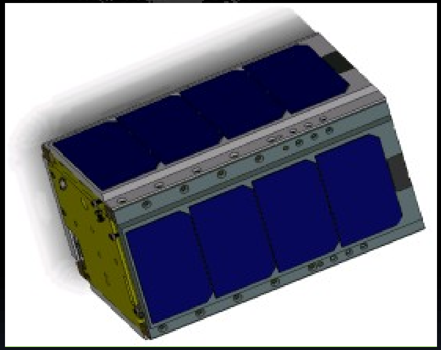




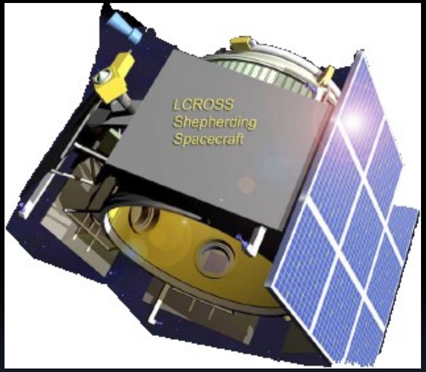
ARC 6U+

O/OREOS

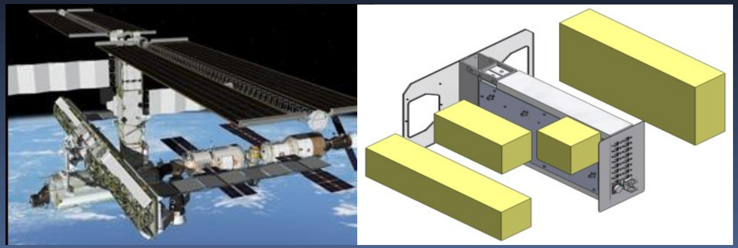




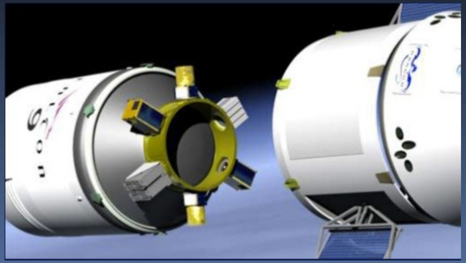
ARC Quad (12U+)



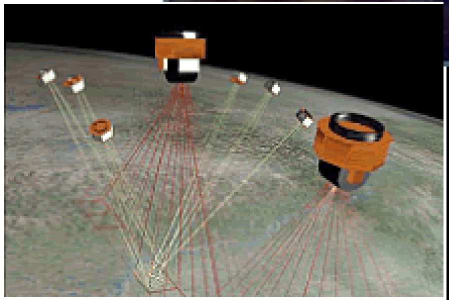
LCROSS

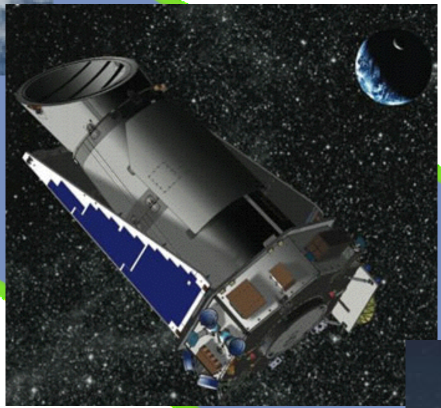


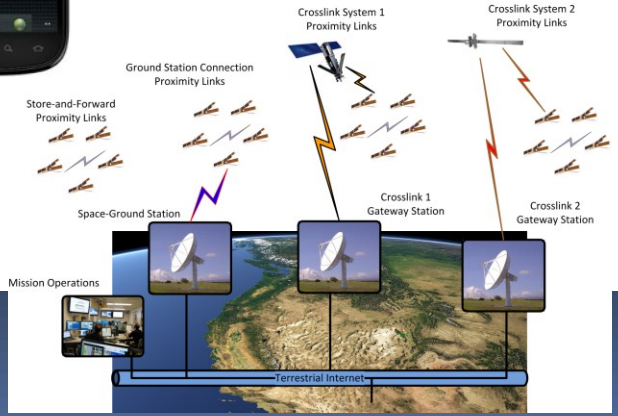
ISS NanoRacks Cubelab

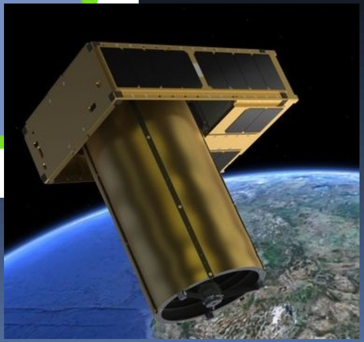


SpaceX
Dragon COTS






Crosslink System 1
Proximity Links
Crosslink System 2
Proximity Links
Ground Station Connection
Proximity Links
Store-and-Forward
Proximity Links
Space-Ground Station
Crosslink 1
Gateway Station
Crosslink 2
Gateway Station
Mission Operations
Terrestrial Internet



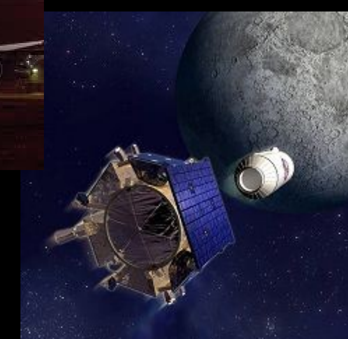
Science: Key Research & Applications Areas

Earth Science

- Atmospheric science
- Biospheric Science
- Applications for Societal Benefit
- Airborne Science
- New Concepts for Earth Science

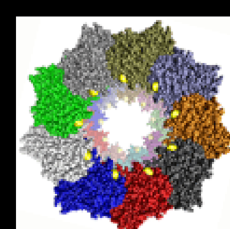
Space Science

- Research
- Advanced Instruments & Sensors
- Missions



Biosciences

- Human Research Program
- Synthetic Biology
- Exploration Life Support
- Radiation & Space Biotechnologies
- Flight Systems Implementation



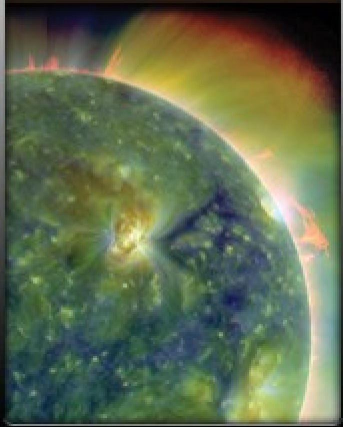
Space Missions Directorate

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

- Inner Solar System
- Outer Solar System
- Small Bodies of the Solar System
- Mars Program Planning

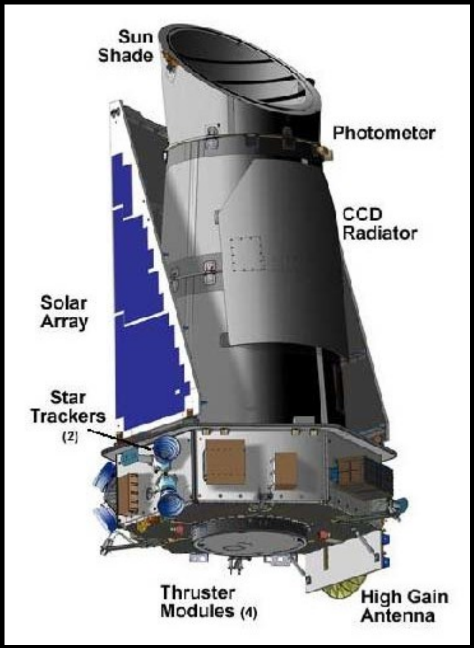
Astrophysics

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

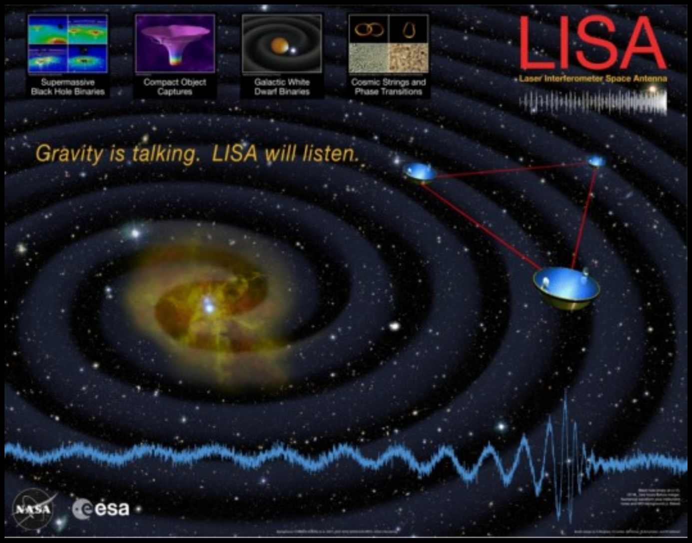
Planets Around Other Stars
The Big Bang
Dark Energy, Dark Matter
Stars
Galaxies
Black Holes

Astrophysics Priorities

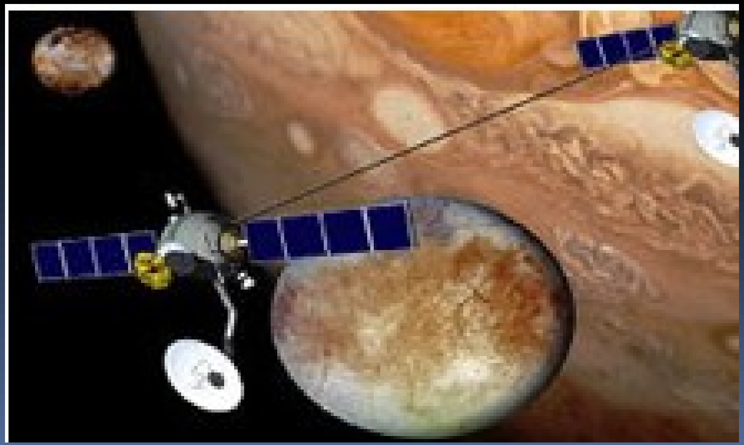
JWST

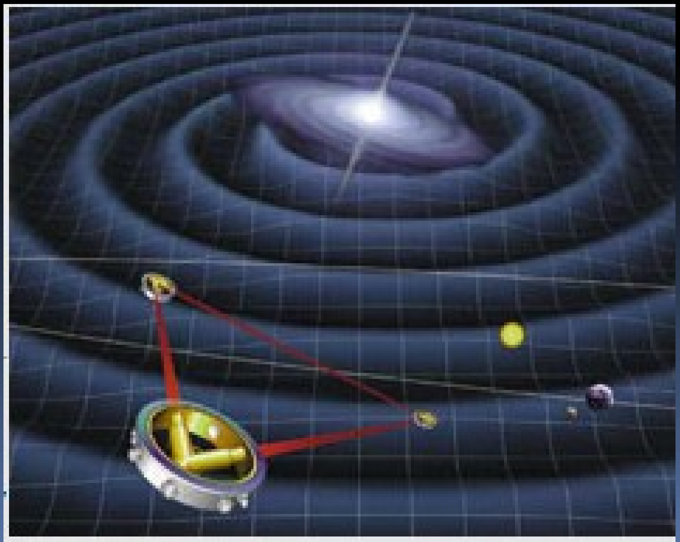


Kepler

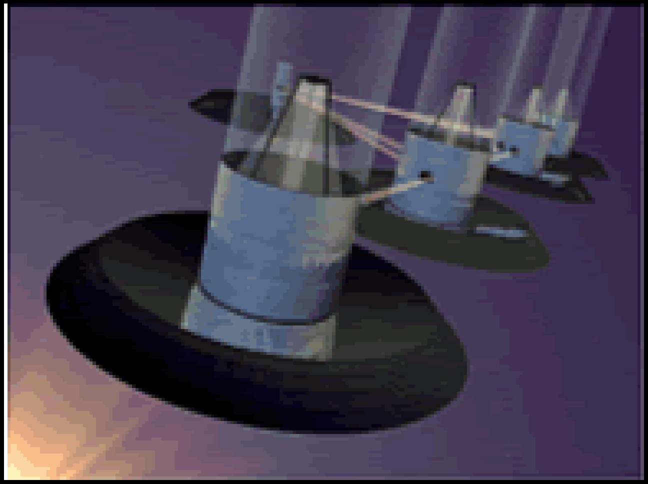


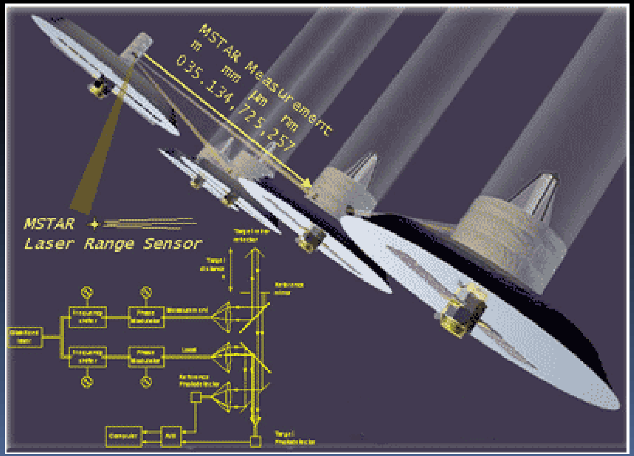
LISA

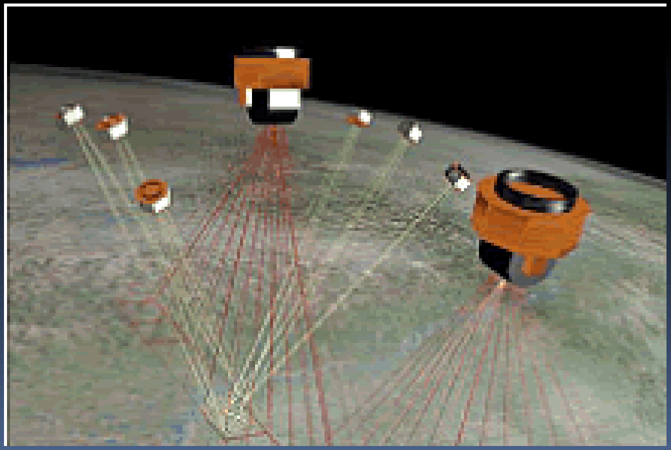




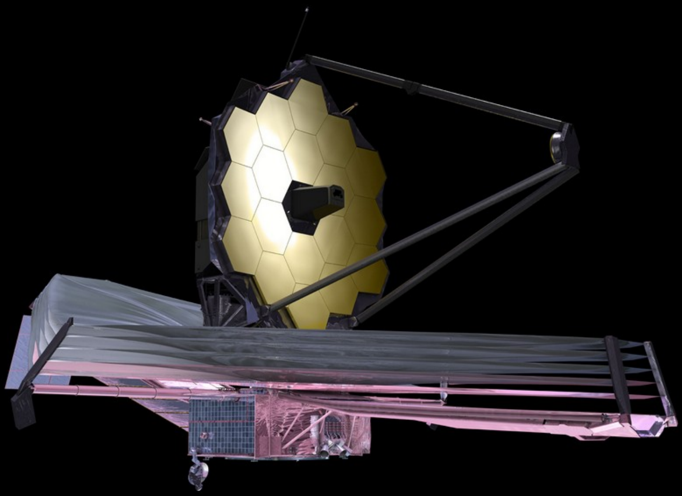
Distributed Spacecraft

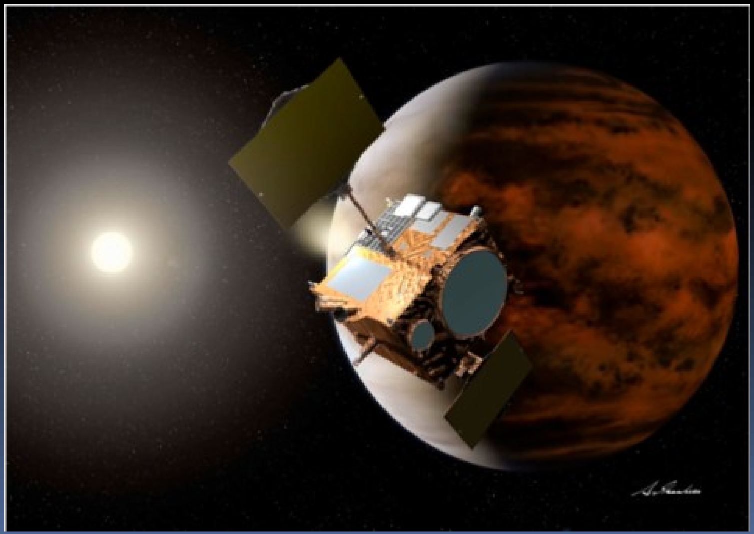




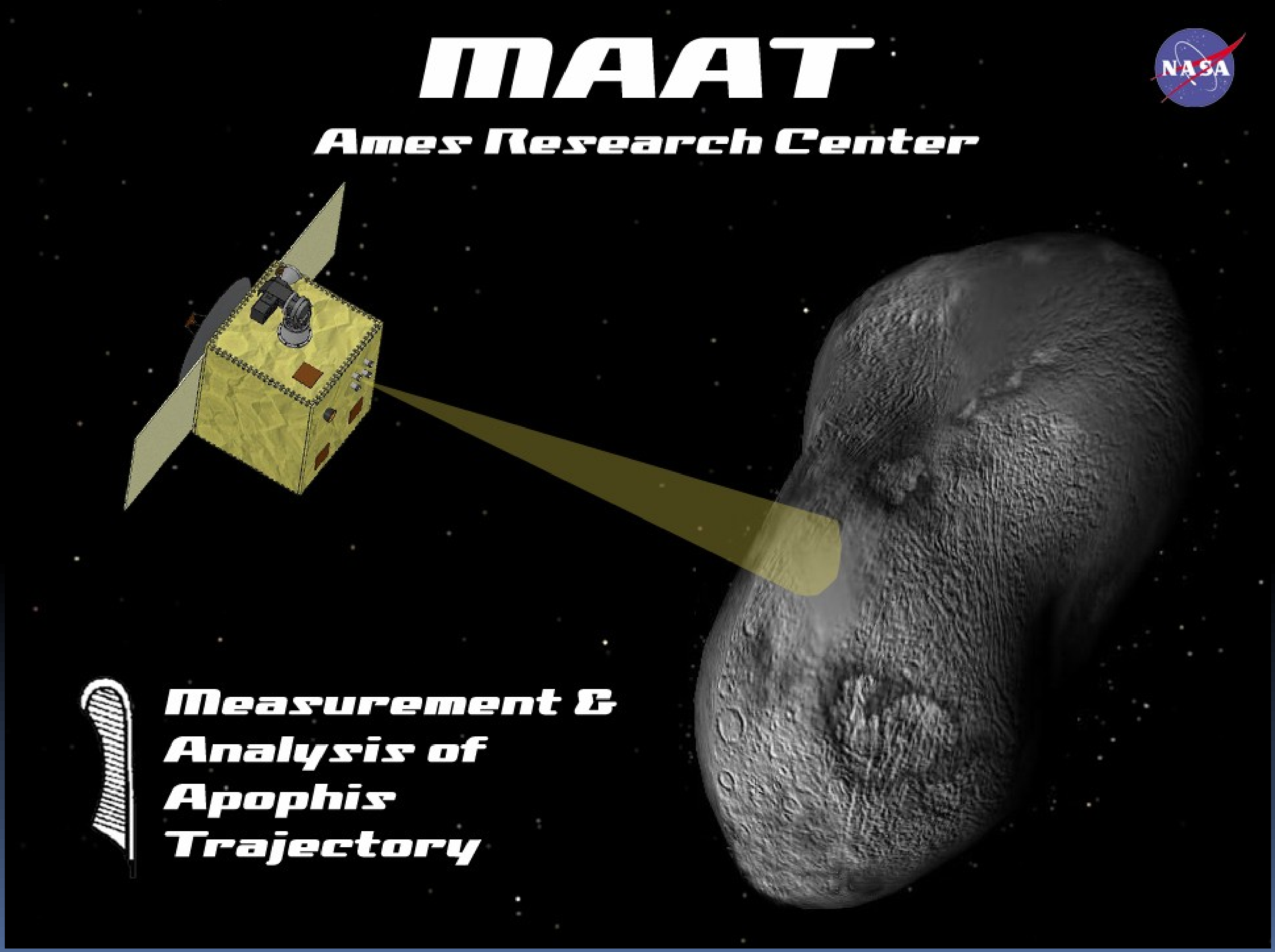


Planetary Science Priorities





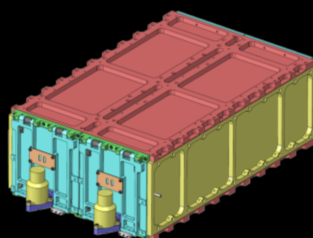
MAAT: Small Satellite Rendezvous and Characterization of Asteroid 99942 Apophis



Planetary Hitch Hiker

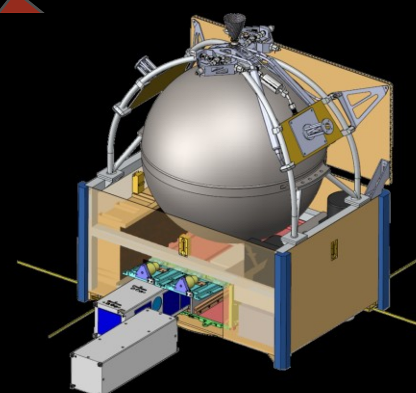
Modularity enables payload, propulsion, and launch flexibility.

Green propulsion

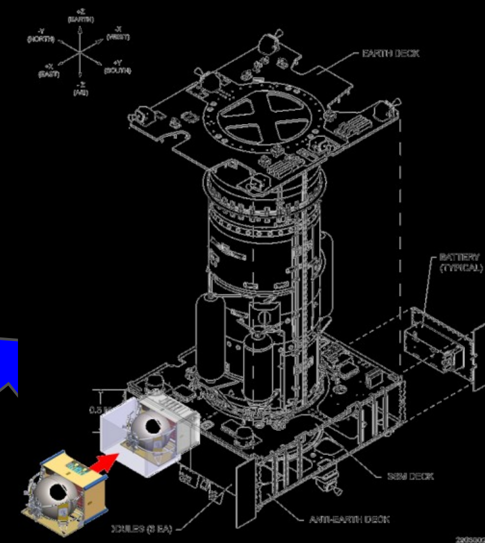


6U nanosat dispenser

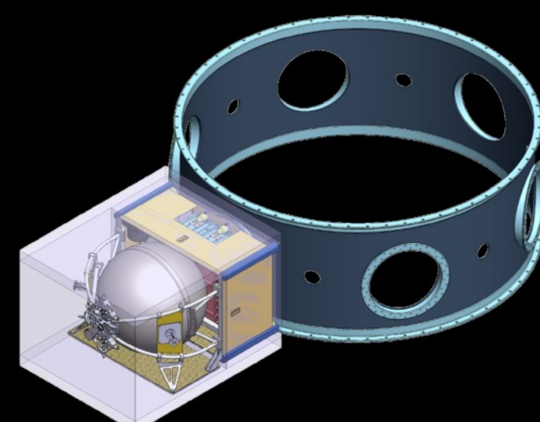
Standardized nanosat payloads



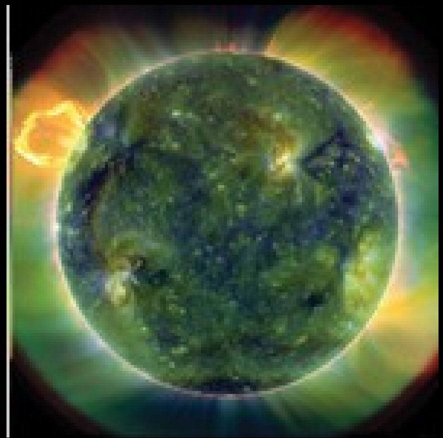
Low-cost and versatile platform

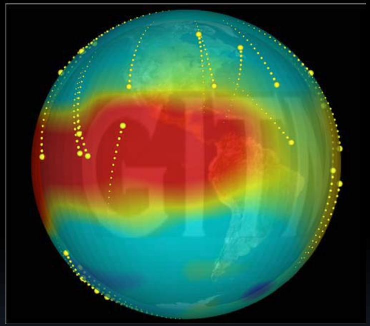


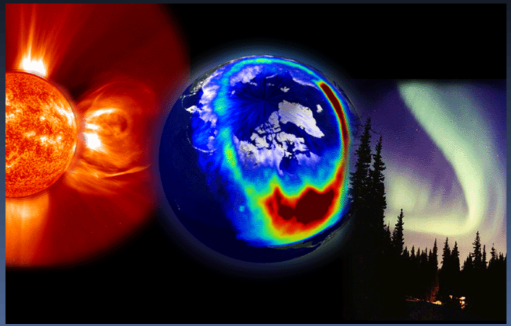
Comsat and ESPA Compatible

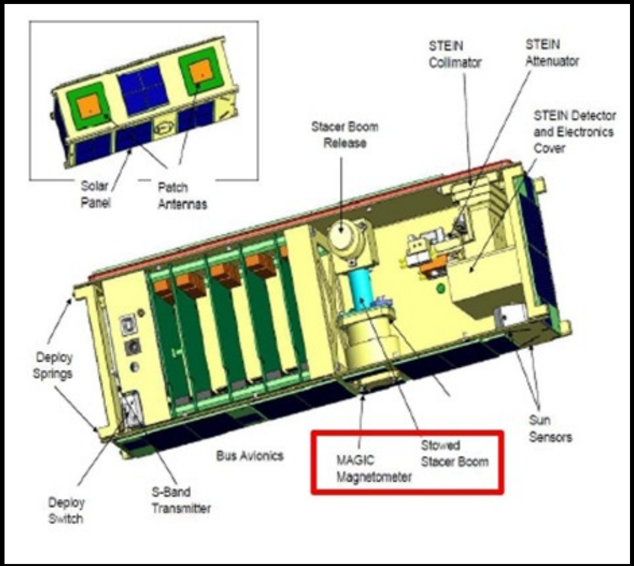


Heliophysics Priorities

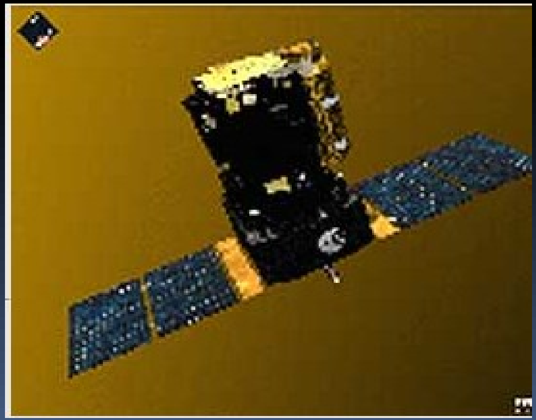




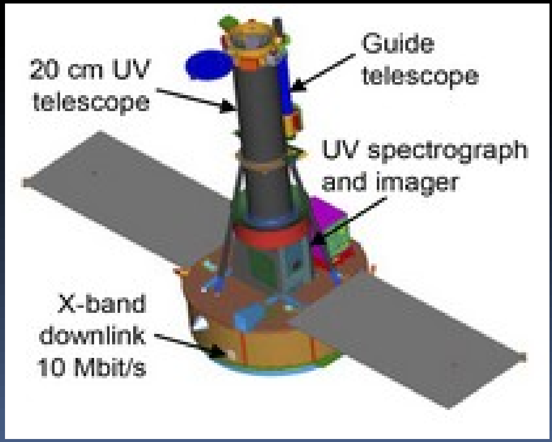




CINEMA



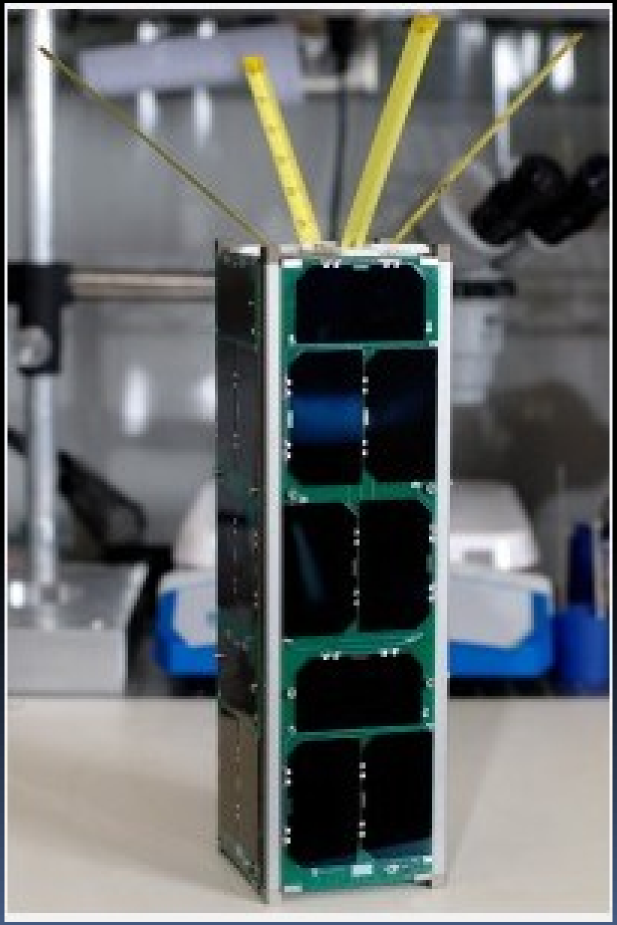
SOHO



IRIS

Cubesats: Space Weather and Thermosphere

SPHERES



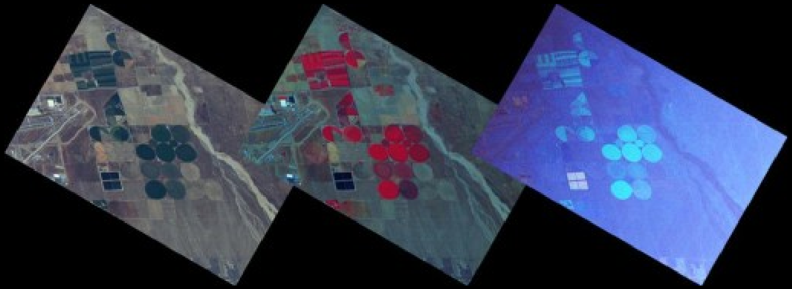
RAX

Earth Science Priorities

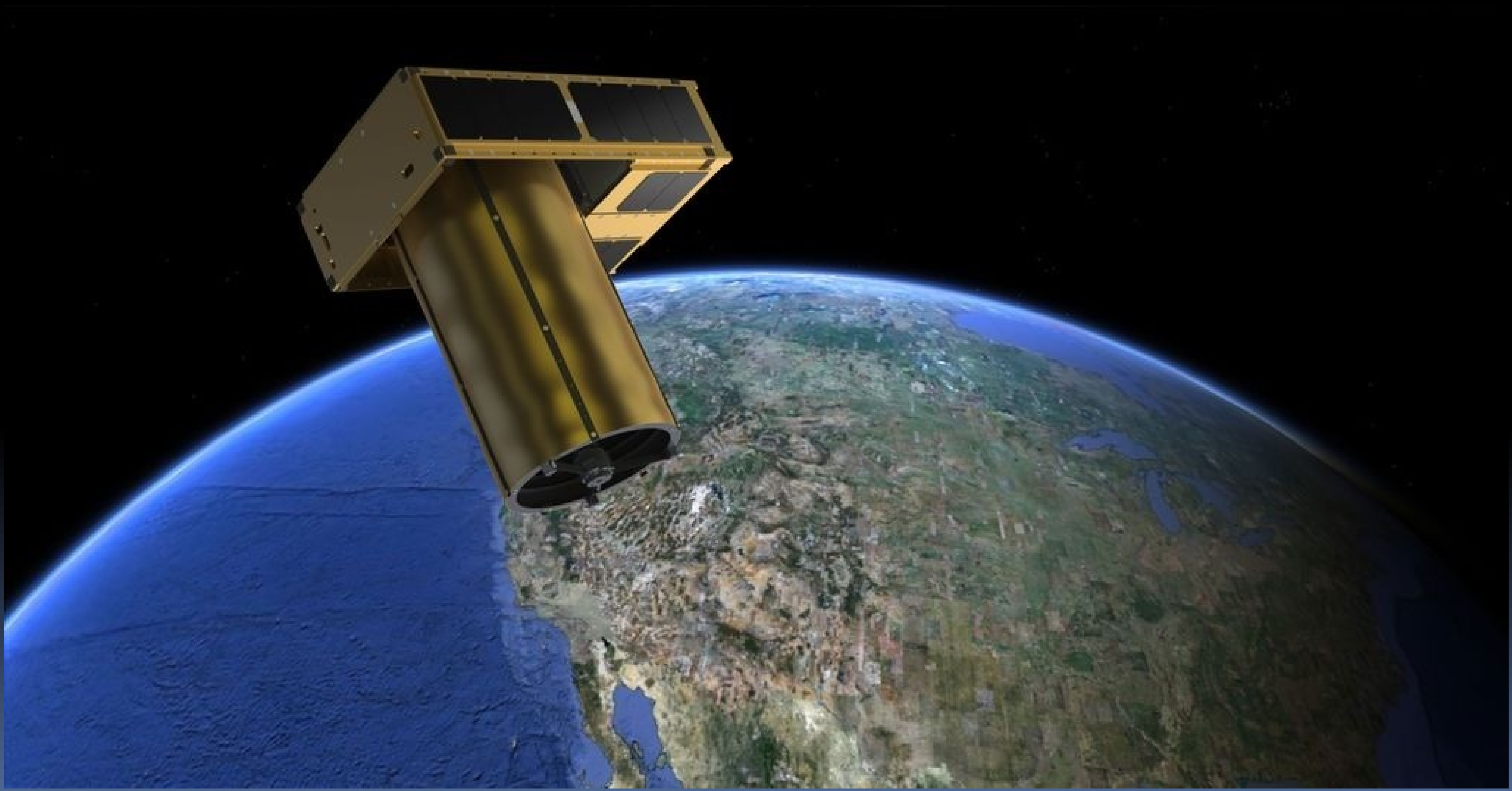
Earth Science: develop a scientific understanding of Earth's system and its response to natural or human-induced changes, and to improve prediction of climate, weather, and natural hazards

- Atmospheric Composition
- Weather
- Carbon Cycle and Ecosystems
- Water and Energy Cycles
- Earth Surface and Interior

Earth Science Programs

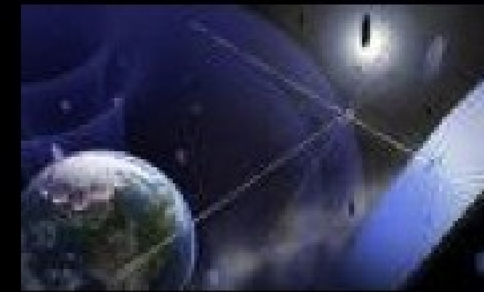


Nanosats: Earth Science and Remote Sensing



Roles of Very Small Spacecraft

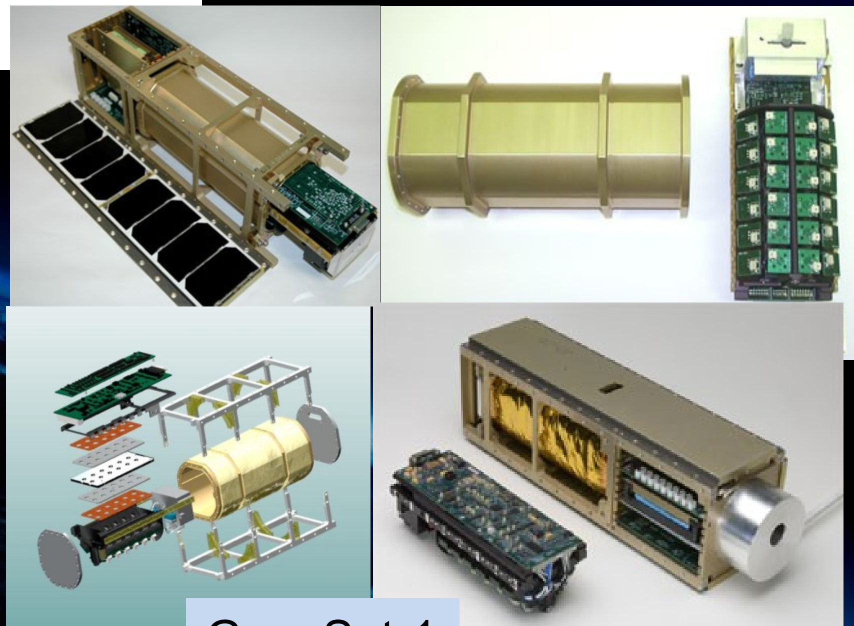
- Science and Exploration Missions
  - **Planetary Science**
  - **Biological Sciences**
  - **Astrobiology**
  - Astrophysics
  - Space Sciences
  - Space Physics
  - Lunar Sciences



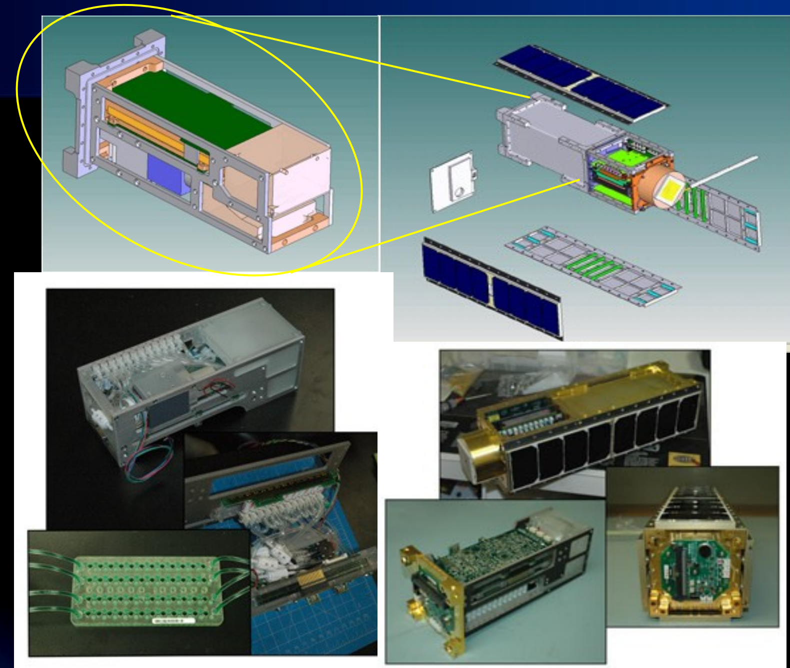
- **Payload packages on larger spacecraft**
  - Flight heritage from Cubesat missions
  - Use Cubesat derived technologies to support other spacecraft missions
    - › *Lunar Orbiters*
    - › *Lunar Landers*

- Technology Demonstrations
  - Propulsion
  - Communications
  - Mass reduction - MEMS and smaller
  - Autonomous operations
  - Formation flying/constellations
  - Novel space architectures - tethers
  - Evolvable, reconfigurable satellites

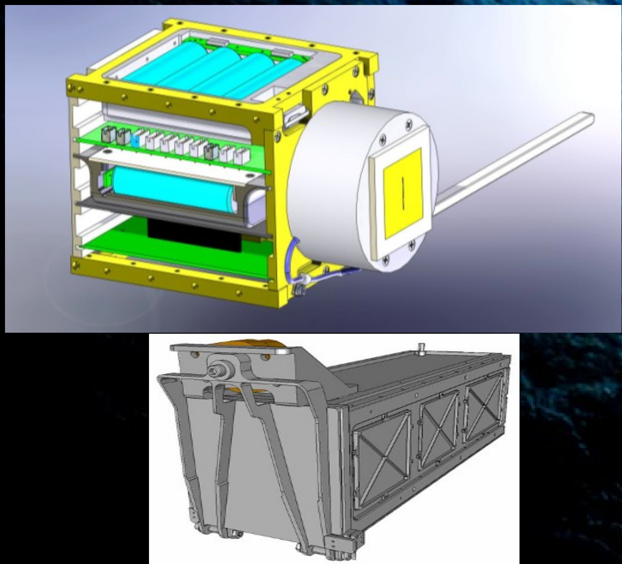
NASA-Ames Nanosatellite Projects

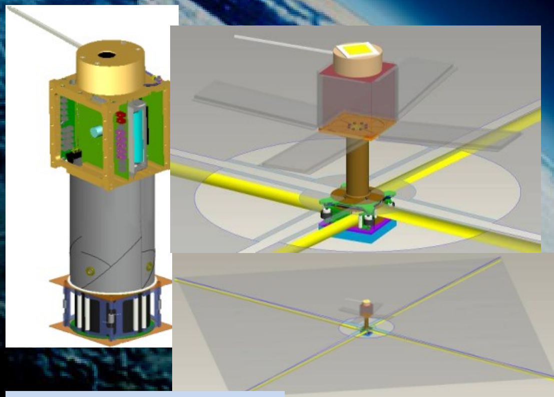


GeneSat-1

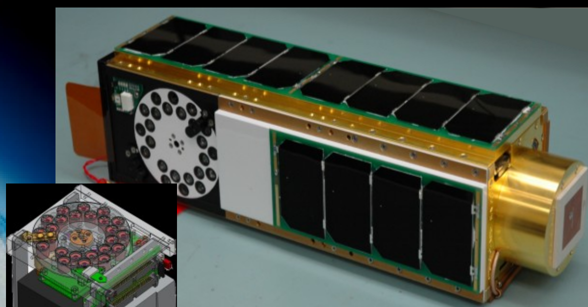


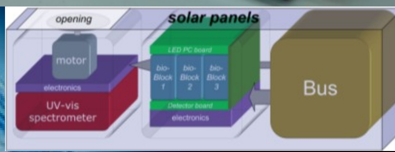
PharmaSat-1





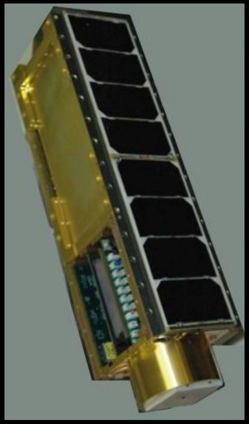
Nanosail-D





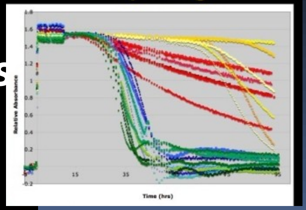
O/OREOS

Pharma& Biotech on Small Satellites



- **Pharmaceutical Efficacy / Drug Development**
  - Dose dependence altered in microgravity: PharmaSat (TRL 8)
    - Voriconazole antifungal less effective at high doses in μ-grav.
    - **May mimic behavior in "biologically difficult" infections**
  - PharmaSat-ECAM (*E.* coli antimicrobial): SALMON MoO-1 (AC Matin, PI)
    - *Hypothesis*: antibiotic resistance of mutant *E. coli* enhanced in μ-gravity
    - **Space-based development/testing of more robust antibiotics**
  - Space environment increases virulence of some pathogens (C. Nickerson)
    - **Proactive ID of virulence targets for drug development**
- **Protein Crystal Growth:** often cited as "killer app"
  - Fewer defects ⇒ better structures ⇒ more effective drugs (site binding)
  - Primary impediments:*sample return*; *reliable & frequent space access*
  - Free-flyers with sample return can address both issues
  - **Advance experiments: grow and "protect" crystals on nanosats**

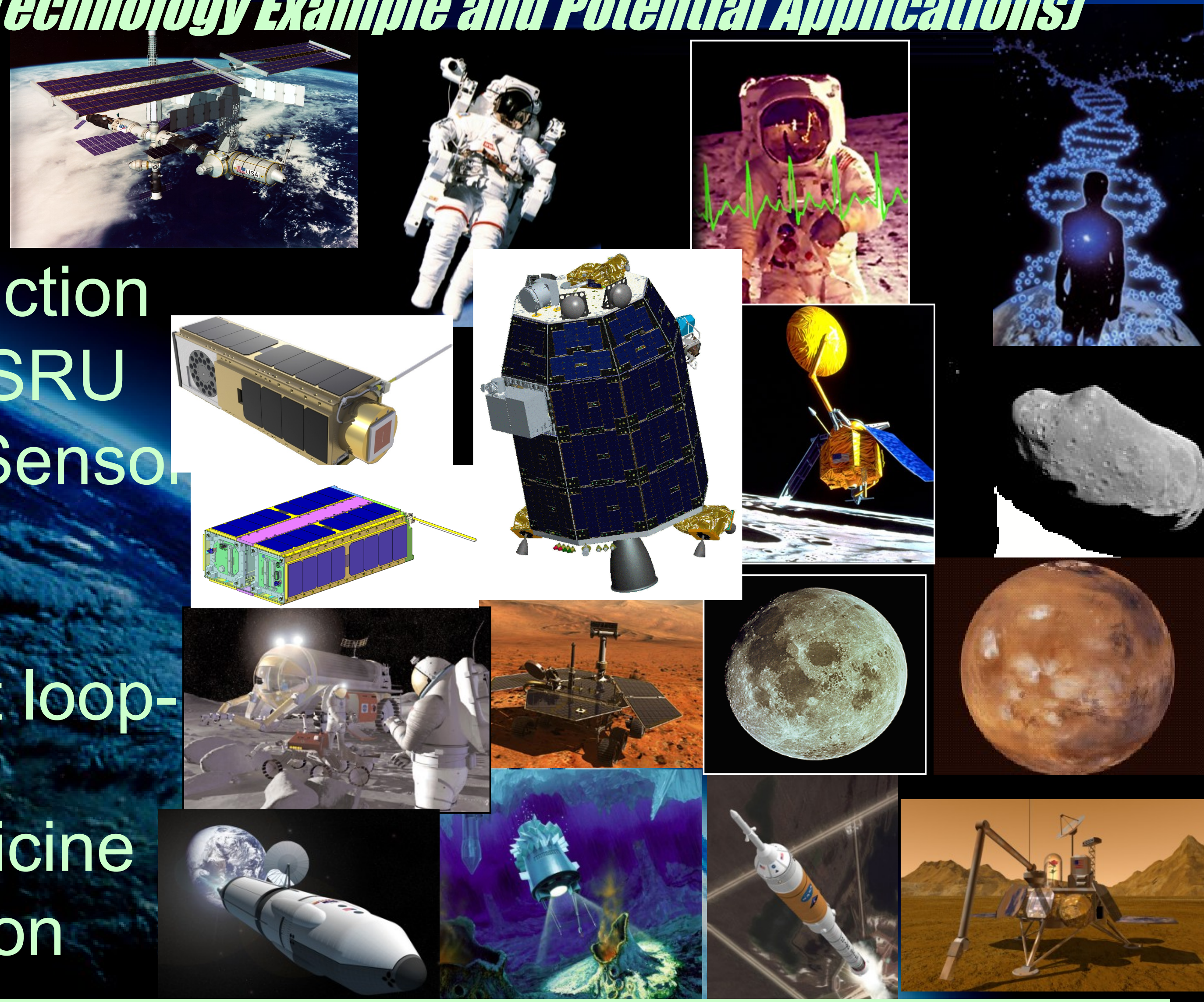
- **Accelerated Test Platform for Afflictions that Need Better Drugs**
  - Loss of bone density
  - Degradation of immune function
  - Muscle atrophy
  - Radiation damage
  - ***Some biological effects are accelerated in space: mechanistic insights can lead to new, more effective terrestrial therapies***



Synthetic Biology

(Disruptive Technology Example and Potential Applications)

- Food Production
- Biological-ISRU
- Advanced Senso
- Advanced Materials
- Life support loop-closure
- Space Medicine
- Life Detection
- Scientifi

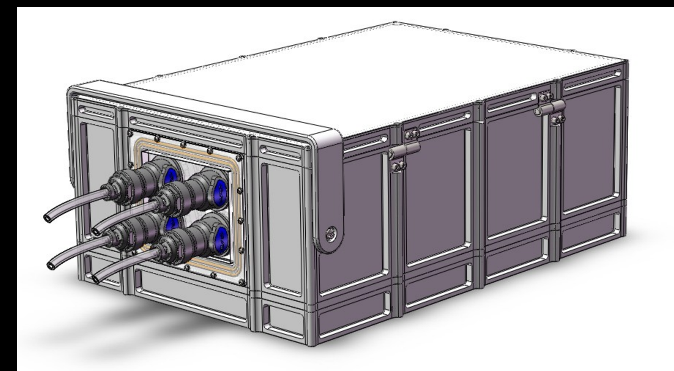


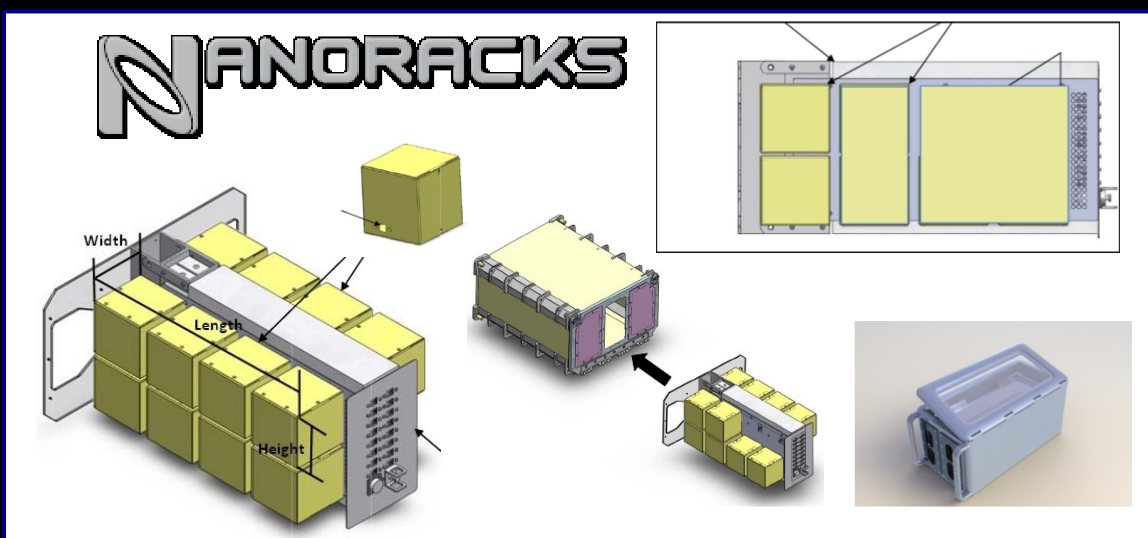
Vision: To harness biology in reliable, robust, engineered systems to support NASA's exploration and science missions, to improve life on Earth, and to help shape NASA's future

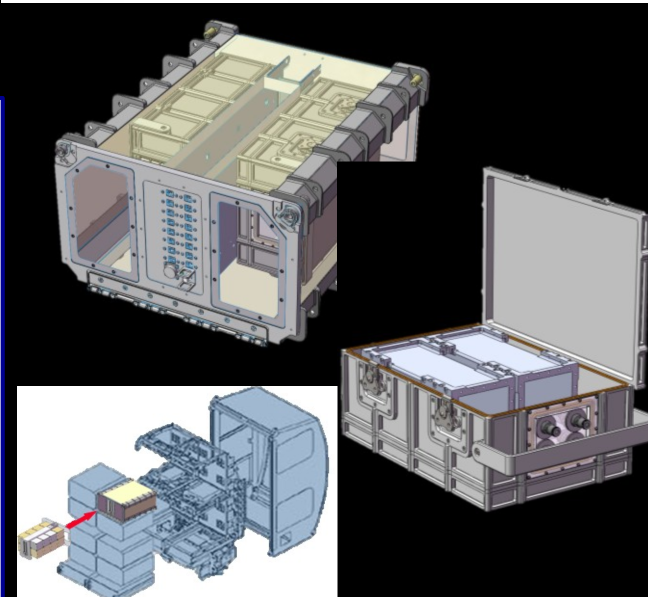
NASA AMES 70 YEARS OF INNOVATION *Platinum Jubilee*

Cubesat Payloads on the ISS

NanoLab



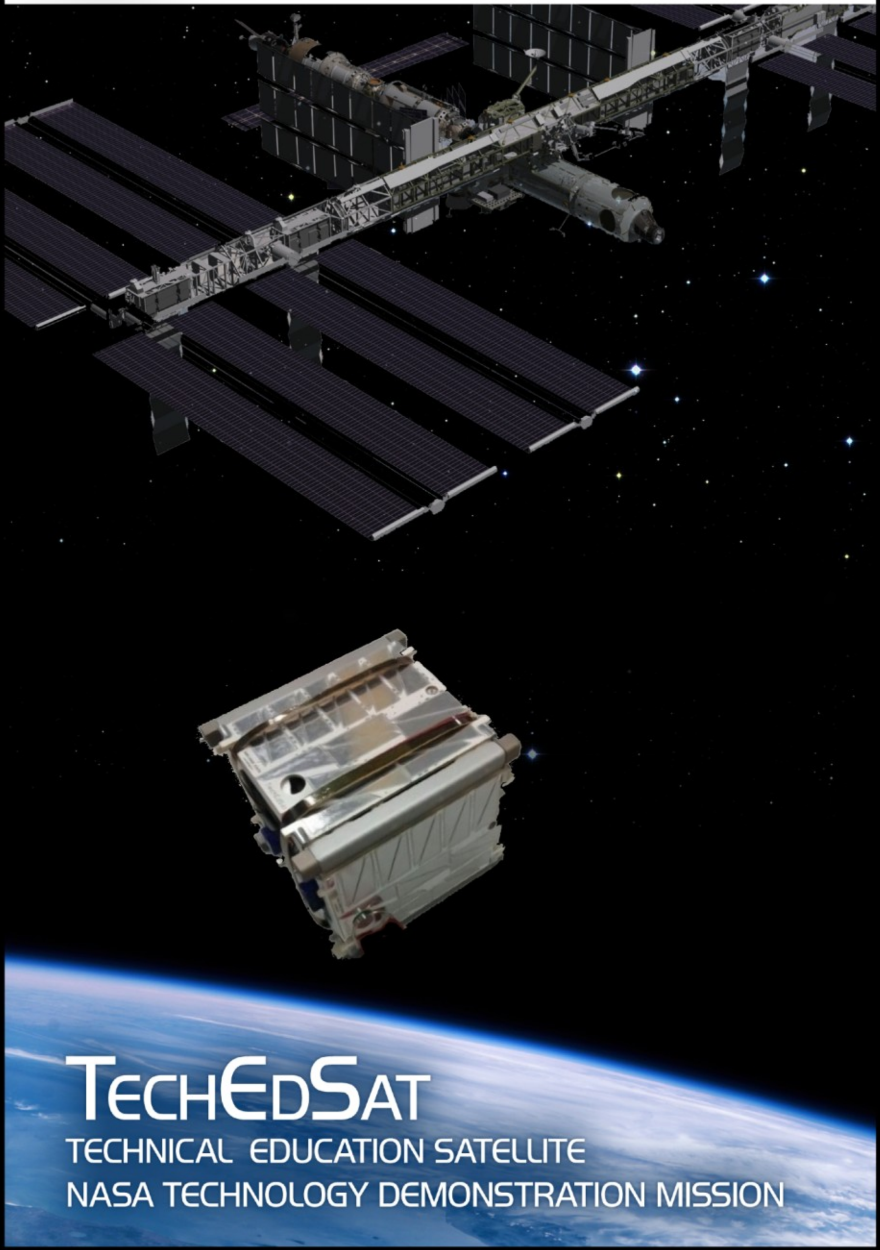




NASA

RYMDSTYRELSEN
Swedish National Space Board

ÅAC Microtec

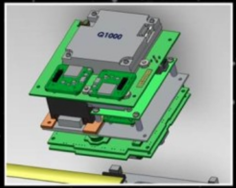


TechEdSat

NASA Technology Demonstration Mission

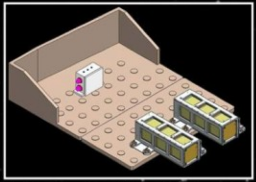
Sponsored by the Office of the Chief Technologist, this mission will demonstrate NASA Ames Research Center's first Space Plug-and-Play Avionics (SPA) satellite with cross-link communications capability.

TechEdSat with the Remove Before Flight pin installed



Internal CAD configuration, showing Quake Global's Q1000 ORBCOMM modem

AAC Microtec's nanoRTU™ device with SPA


Deployer plate with the two Japanese Experiment Module (JEM) Small Satellite Orbital Deployer (J-SSOD) cases installed

TechEdSat will deploy from the J-SSOD in 09/2012


Japan Aerospace Exploration Agency (JAXA) JEM Remote Manipulator System with the two J-SSOD's deploying CubeSats

Project Schedule

- PDR Date: 12/02/2011
- CDR Date: 04/10/2012
- Hardware Delivery Date: 05/12/2012
- Launch Date: 06/26/2012
- Release from ISS: 09/2012
- End of Mission: Approximately 12/17/2012

San Jose State University Team

Front row left to right: Marcus Murbach, Periklis Papadopoulos, Michelle Mojica, Adrianna Aguilar, Alyssa Villanueva, Gabriel Alvarez, and Greenfield Trinh

Middle row left to right: Bob Ricks, Aaron Cohen, Ali Guarneros Luna, Darryl LeVasseur, Cameron Bounds

Top row left to right: Andres Martinez, Jose Cortez

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AAC Microtec Team

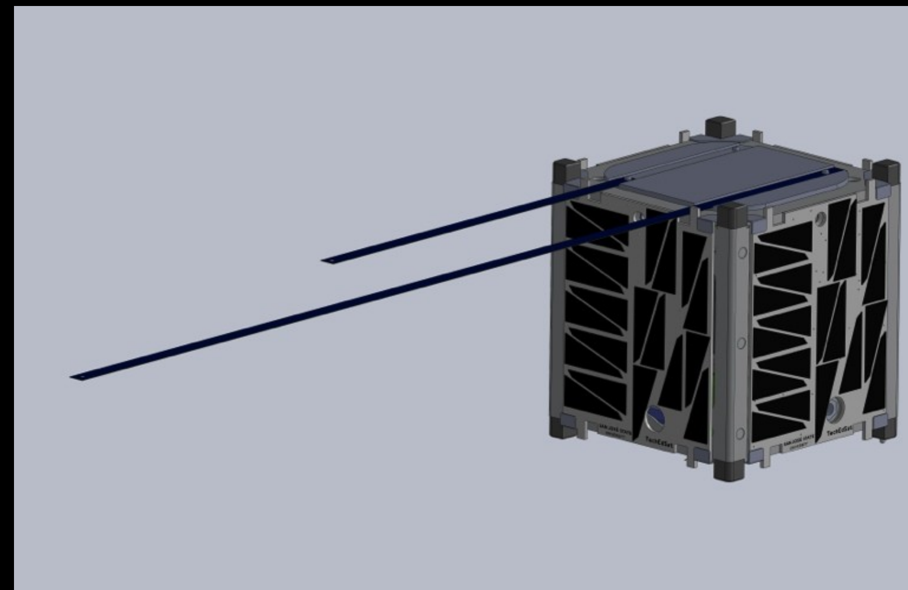
Henrik Löfgren, Per Selin, Jan Schulte

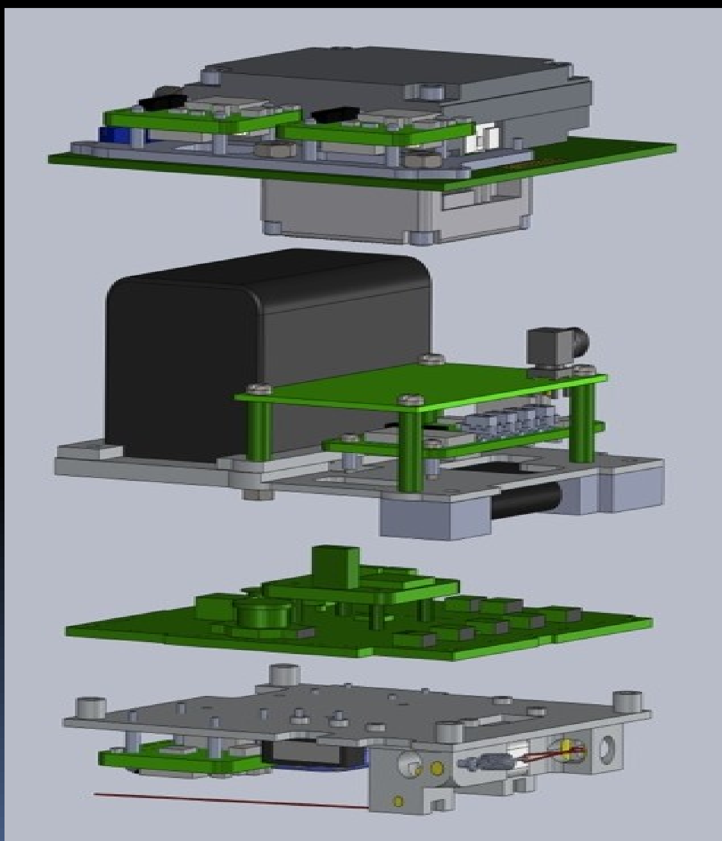
NASA acknowledges the contributions of the following:

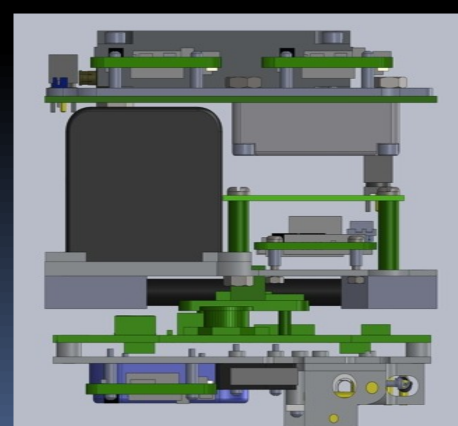
NCASST JAXA agi SPACE SYSTEMS LORAL

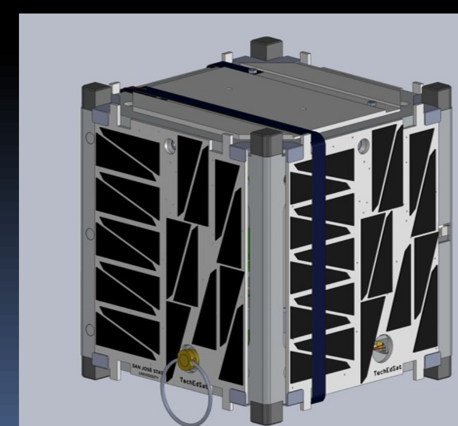
TechEdSat-1.1

Launch 21JUl2012

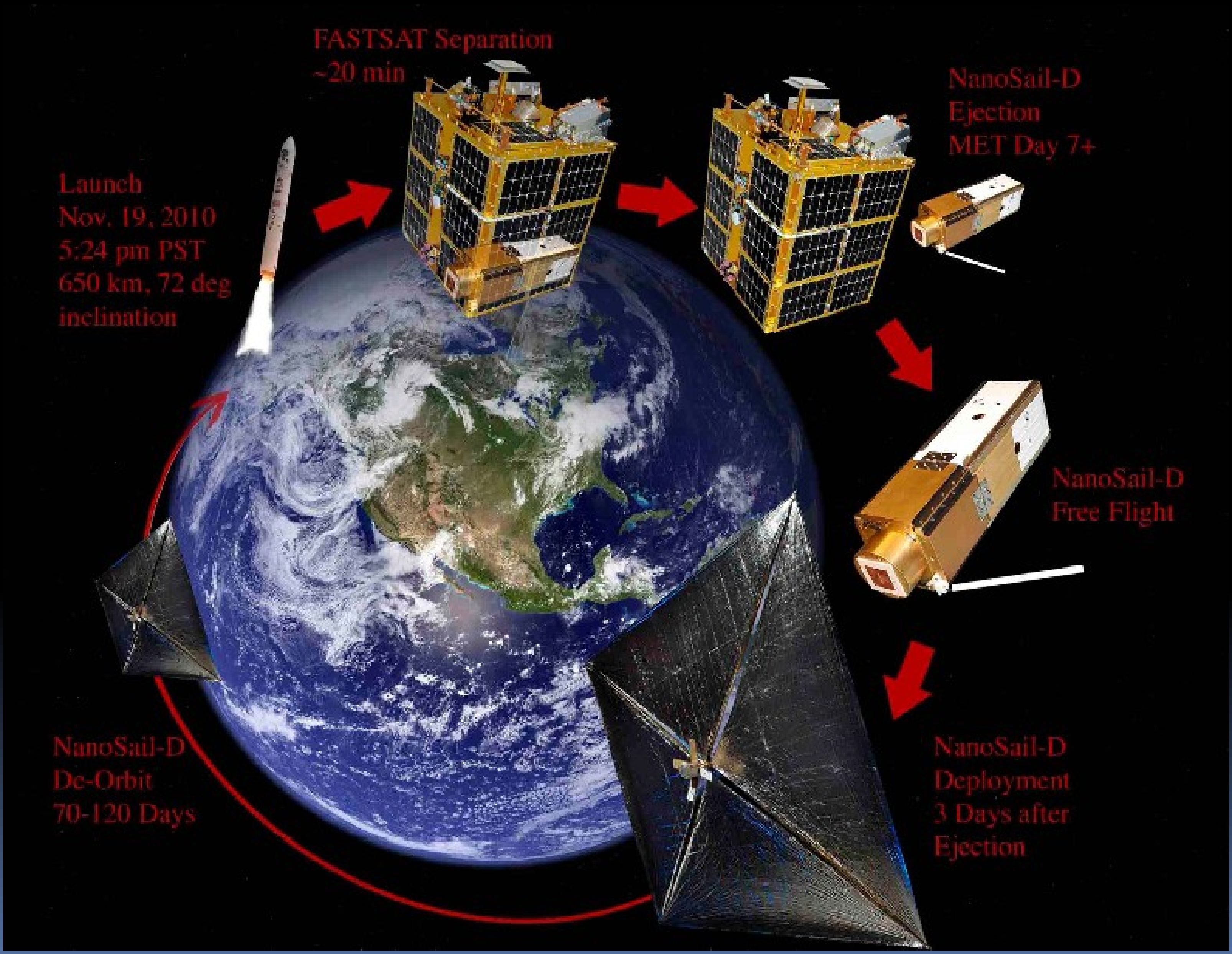




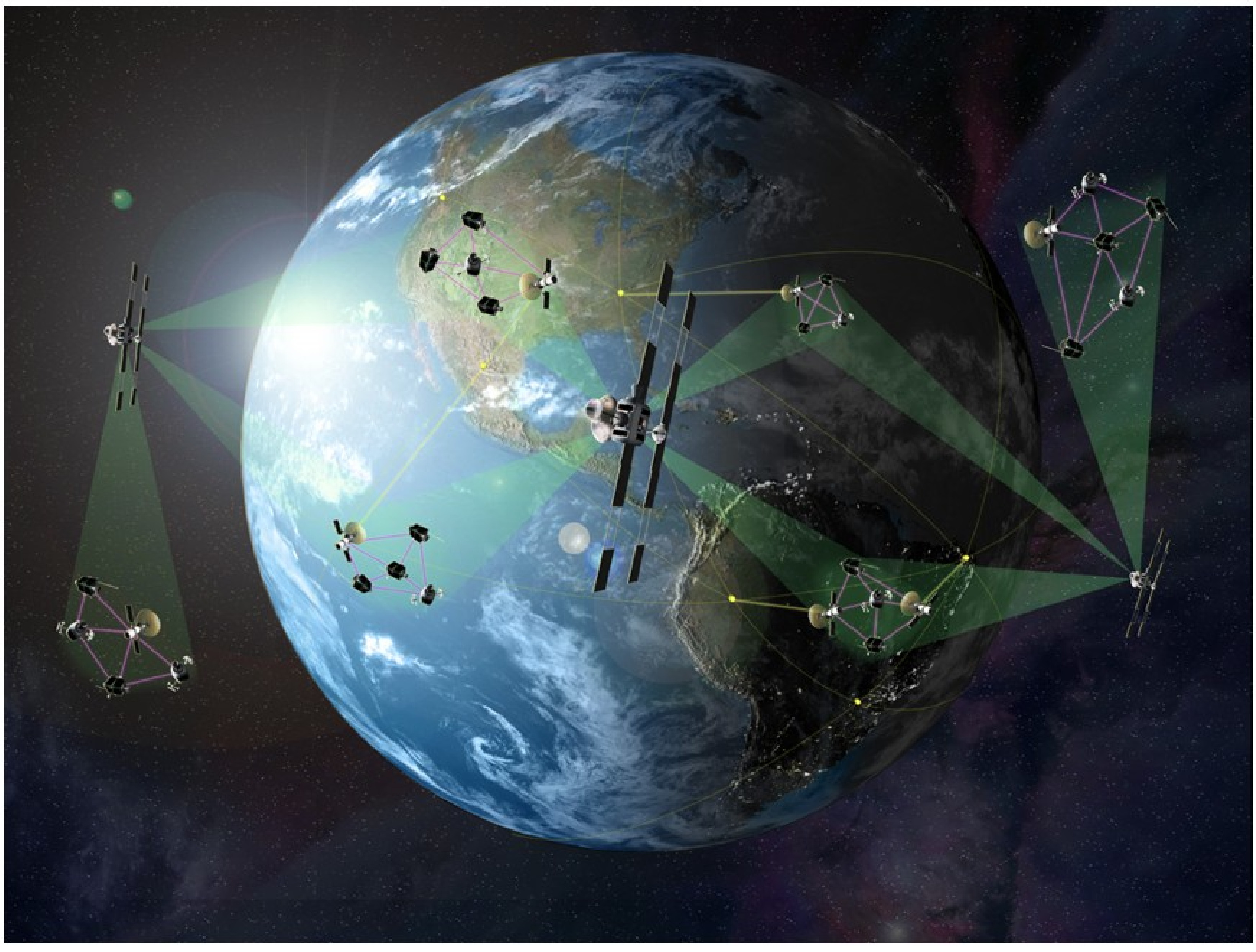




Nanosail D


FASTSAT Separation
~20 min
NanoSail-D
Ejection
MET Day 7+
Launch
Nov. 19, 2010
5:24 pm PST
650 km, 72 deg
inclination
NanoSail-D
Free Flight
NanoSail-D
De-Orbit
70-120 Days
NanoSail-D
Deployment
3 Days after
Ejection

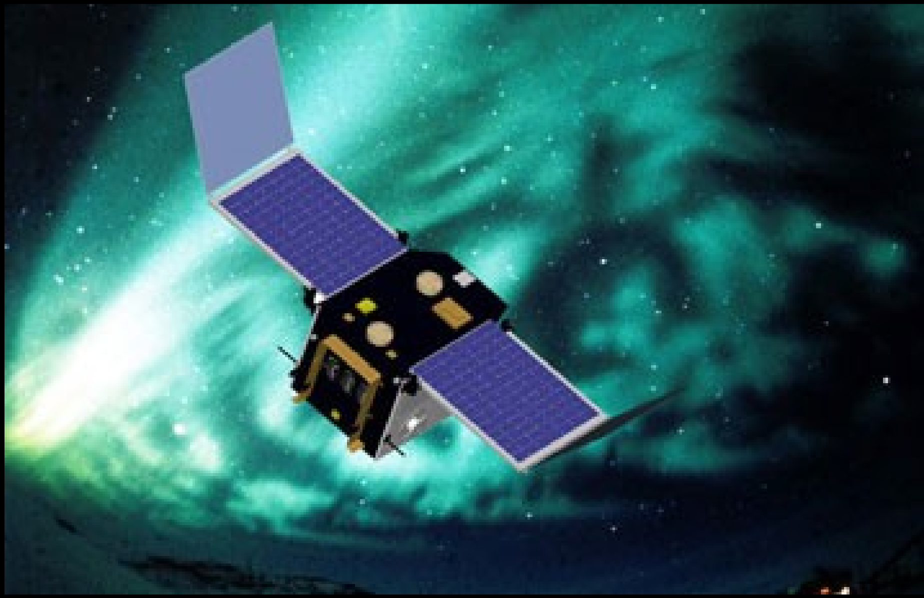
DARPA F6 Program



INnovative-technology Demonstration Experiment REIMEI (JAXA 2005)

The "Reimei" (INDEX) is a small scientific satellite that was launched as a piggyback on the Dnepr Launch Vehicle from Baikonur Cosmodrome in the Republic of Kazakhstan at 6:10 a.m. on August 24, 2005 (Japan Standard Time.)

REIMEI will perform in-orbit demonstrations of cutting edge satellite technology over a brief period of time, it will carry onboard instruments for physical observation suitable for a small satellite, aimed at obtaining the world's most advanced scientific results.



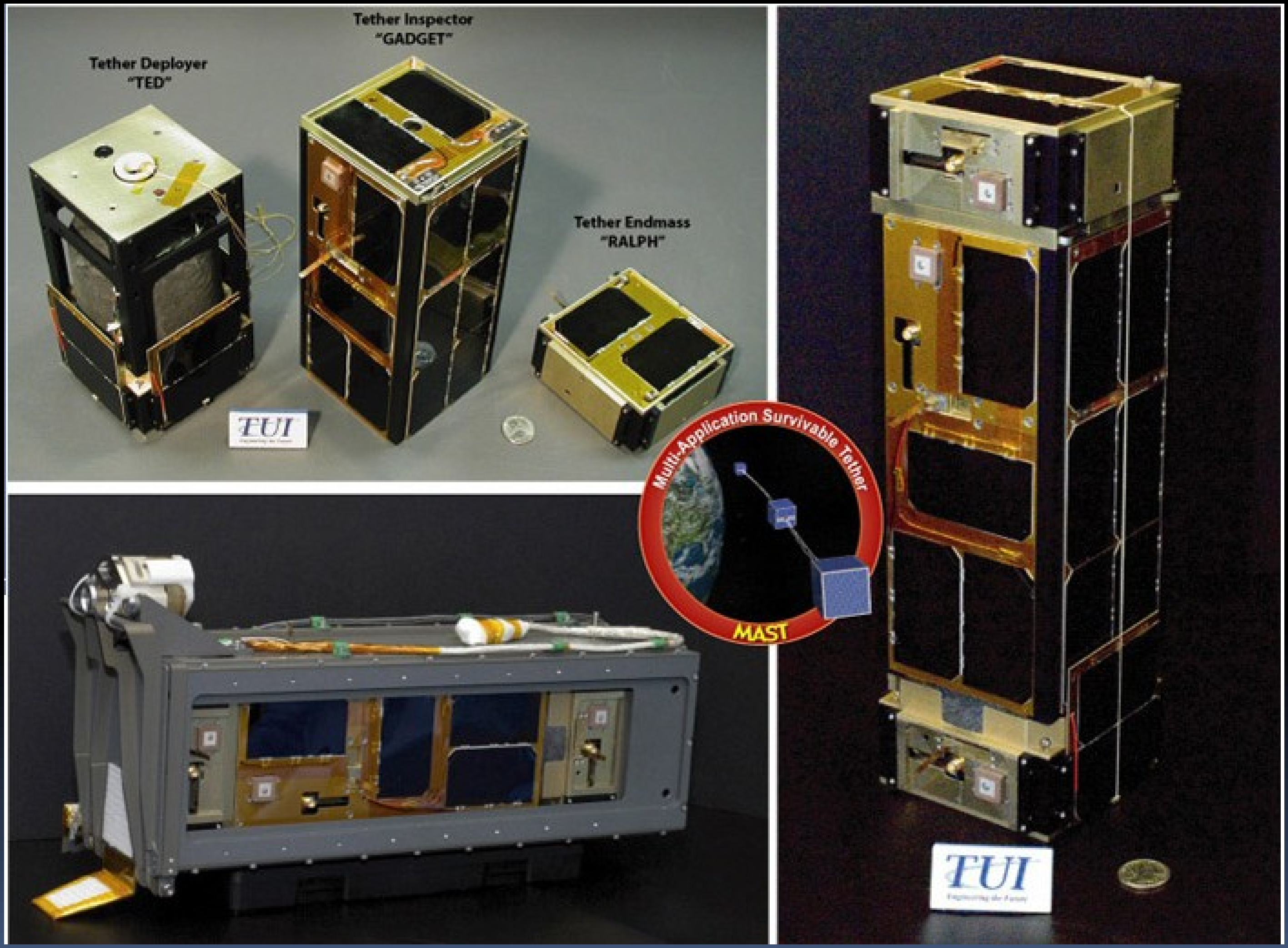
.Actively verifying latest engineering technology and observing auroras through scientific observation methods. Not all scientific missions require a large-size scientific satellite. In the astronomical satellite field, small satellites are not popular as an aperture of a telescope must be installed.

REIMEI aims to verify the high-performance and high-accuracy attitude control for a small satellite.

Major Characteristics

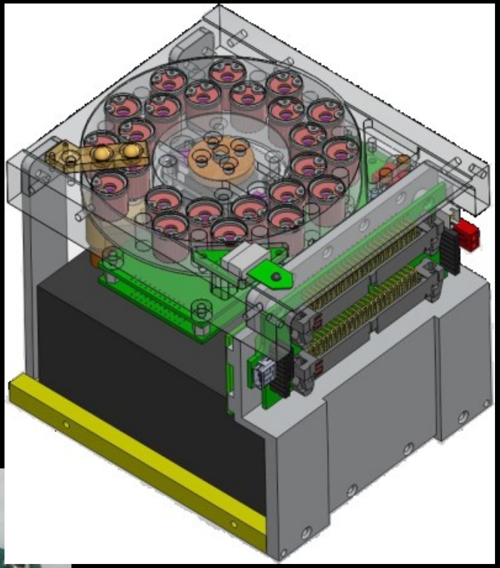
International Designation Code	2005-031B
Launch Date	06:10, August 24, 2005 (JST)
Launch Vehicle	Dnepr launch vehicle
Location	Baikonur Cosmodrome, Kazakhstan
Shape	60cm x 60cm x 70cm
Weight	60kg
Orbiter	Quasi-circular orbit
Altitude	Perigee 610 km, Apogee 654 km
Inclination	97.8 degrees
Period	97 minutes
Attitude Control	Three-axis stabilization (Bias momentum method)

Cubesats:


Tether Inspector
"GADGET"
Tether Deployer
"TED"
Tether Endmass
"RALPH"
TUI
Multi-Application Survivable Tether
MAST
TUI

Spectroscopy on Small Satellites

- O/OREOS NanoSat UV/visible

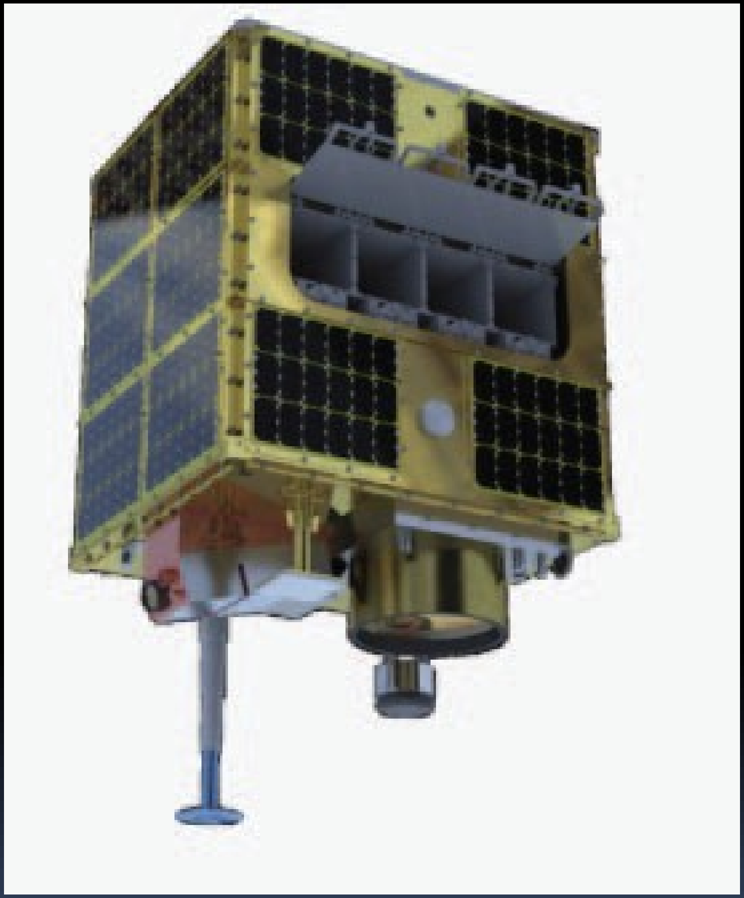


- LCROSS MEMS-Based NIR

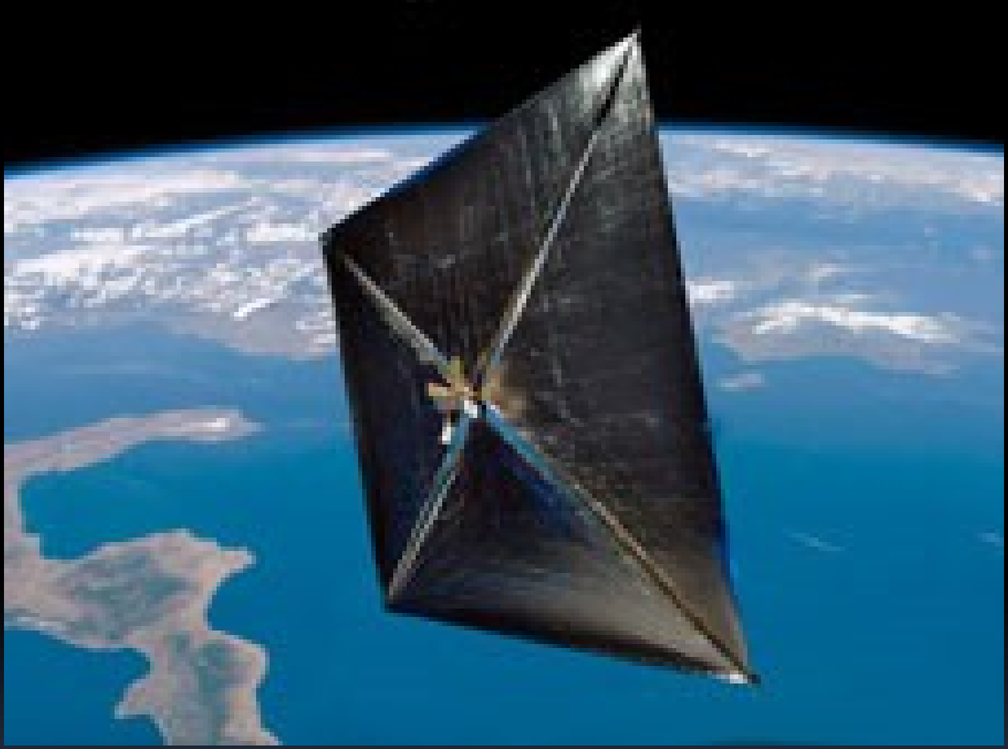
Cubesats: Technology Architectures and Demos

- Plug and Play
- Arrays
- Instruments
- COTS (e.g., phonesats)

Nanosatellite Deployment from Microsatellite

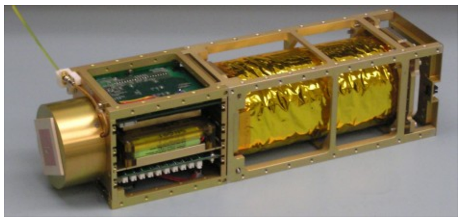


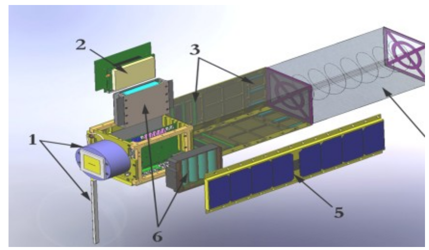
FASTSAT



http://www.nasa.gov/mission_pages/smallsats/nanosaild.html

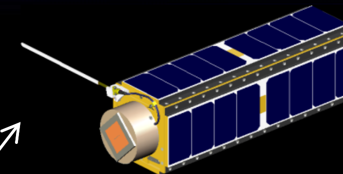
<u>MesoScale</u> Micro-Nano Satellite Option

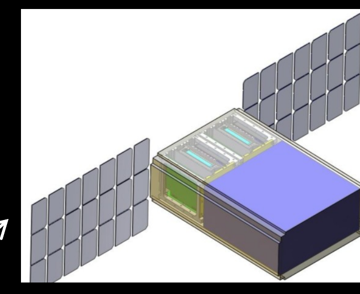


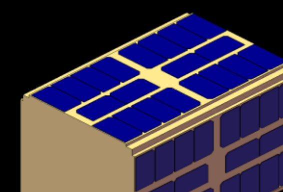


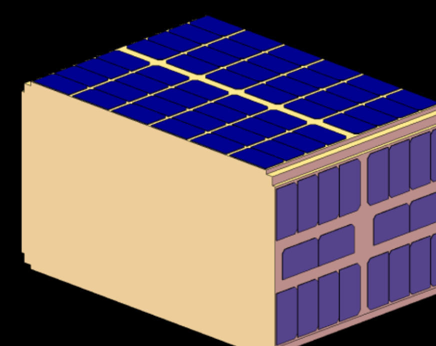
– Maximum 2.0 kg per cube equiv or 6.0 kg.
– Triple cube equiv baseline designated as 1N, configs = 1N, 2N, 3N, 4N.
– 4N quad = 1Q; 1Q =4 ea 1N in 2x2 (or 1x4) form factor;
– Configs = 1Q, 2Q, 3Q (Special cases only right now).
– Maybe also 1.5 Q (= 32N). (Special cases only)

Mass (kg)	Name	Vol
6	NanoCube	1N
12	2Cube	2N
24	Quad (2x2)	1Q
48	Double Quad	2Q



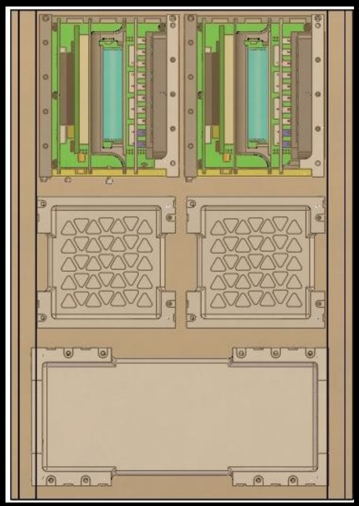


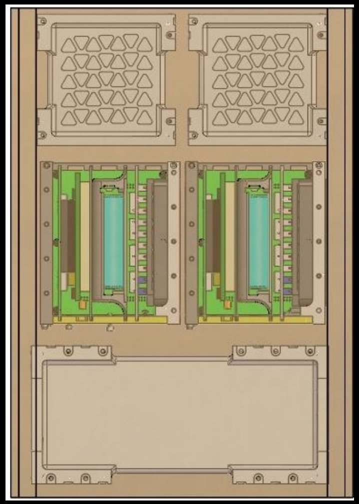


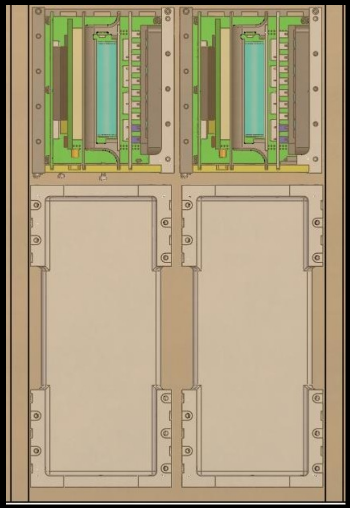


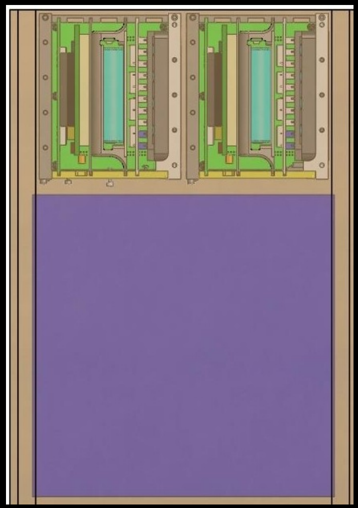
6-Pack Nanosatellite Possible Configurations (2N/6Cube)

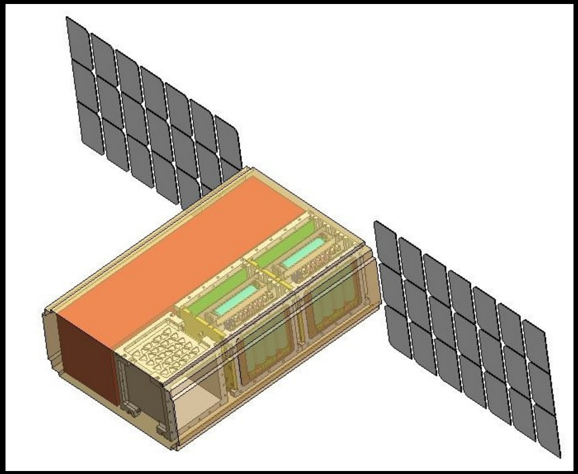
[assumes 2U equivalent bus, 4U payload volume]

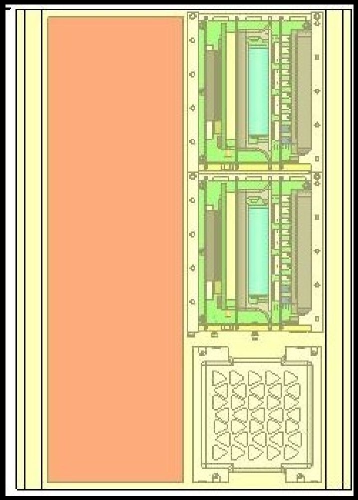


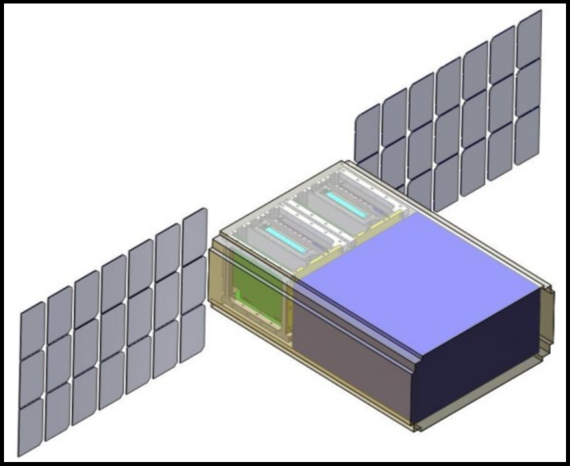




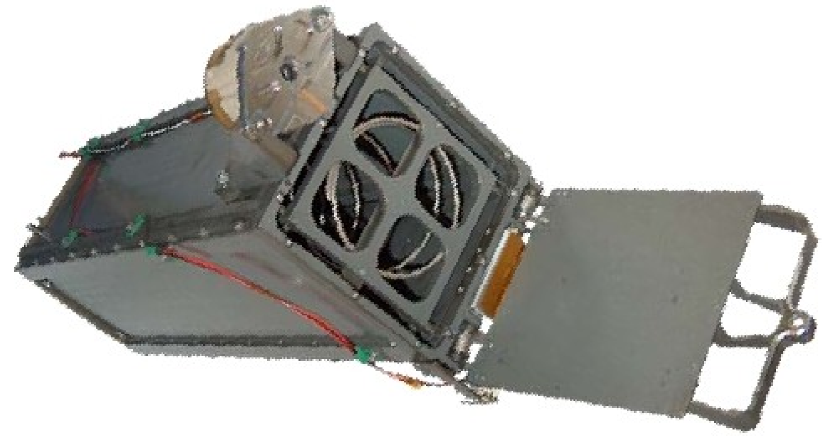


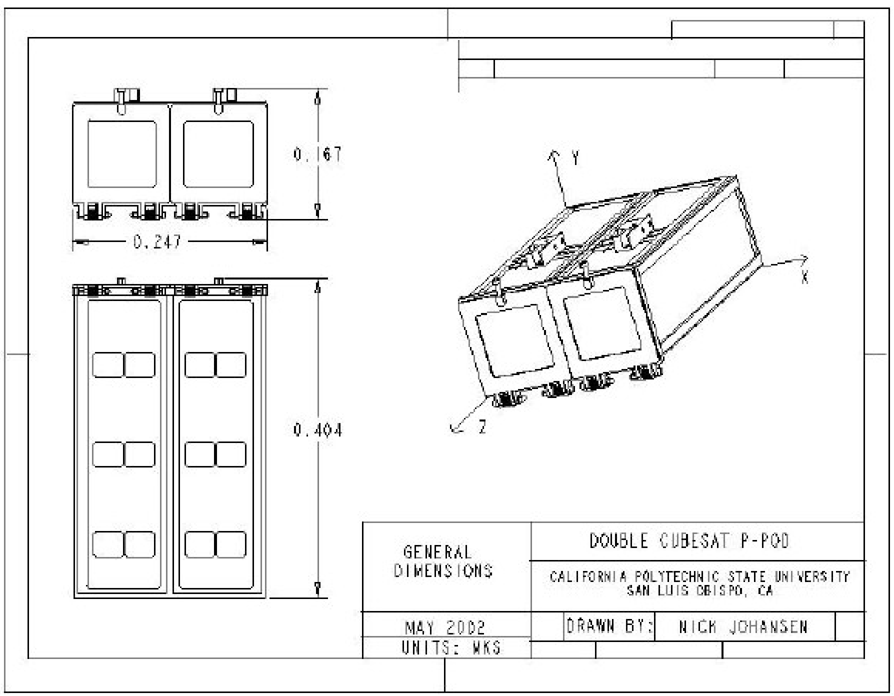


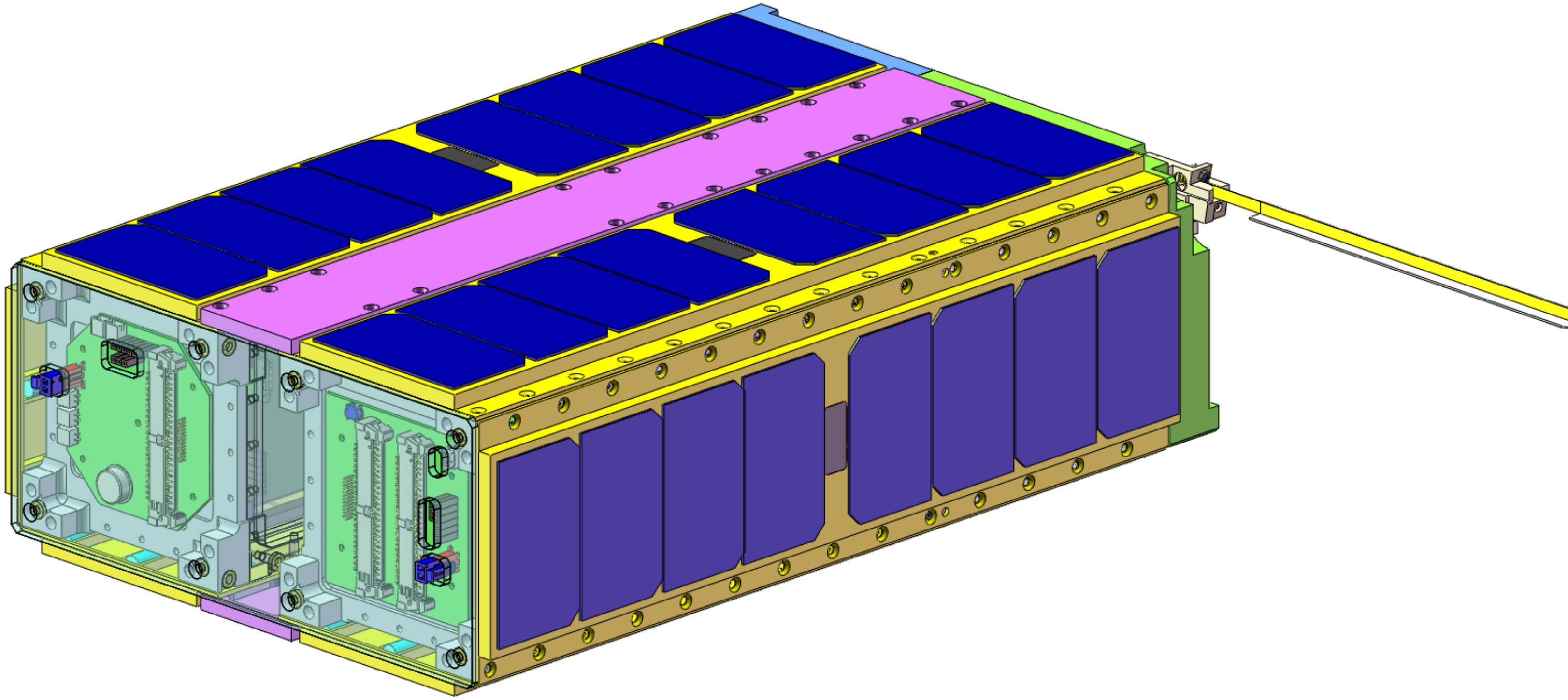


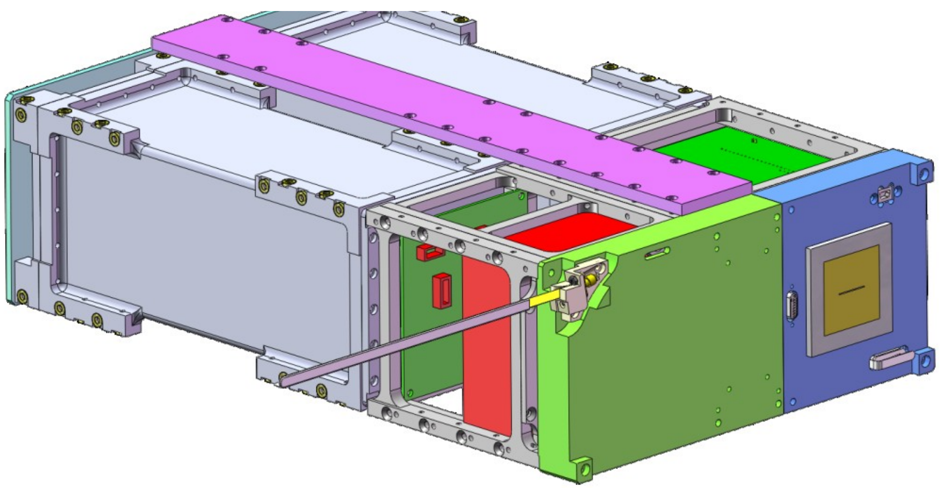


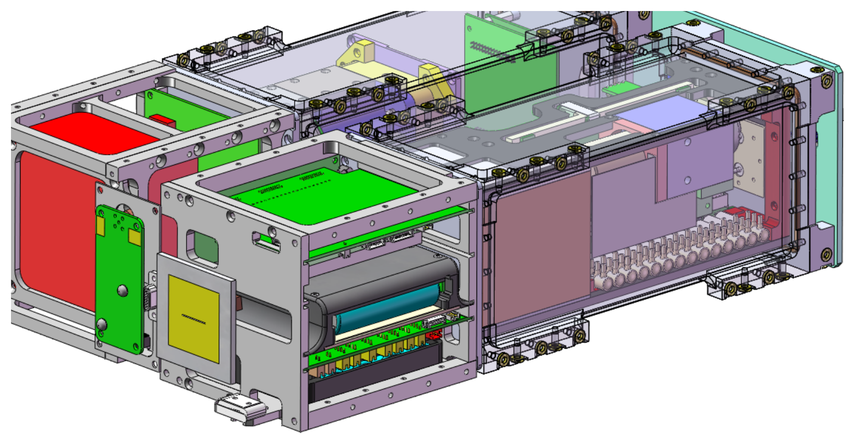
ARC 6U+ Design Strategy





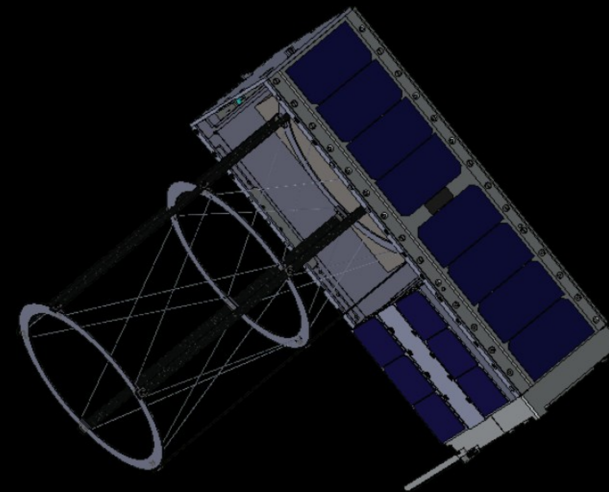






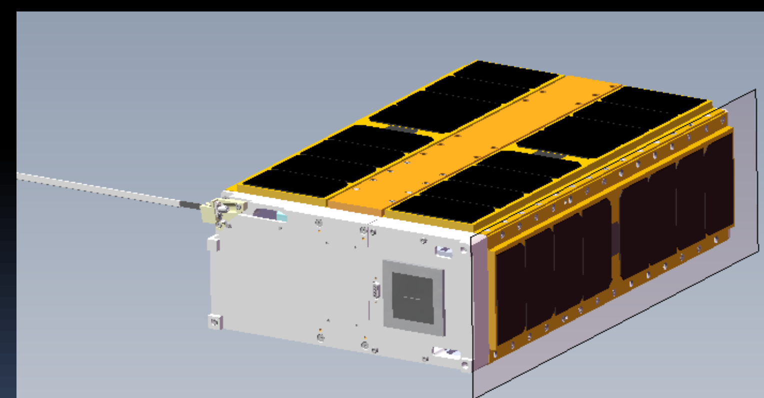
Collapsible Dobson Space Telescope

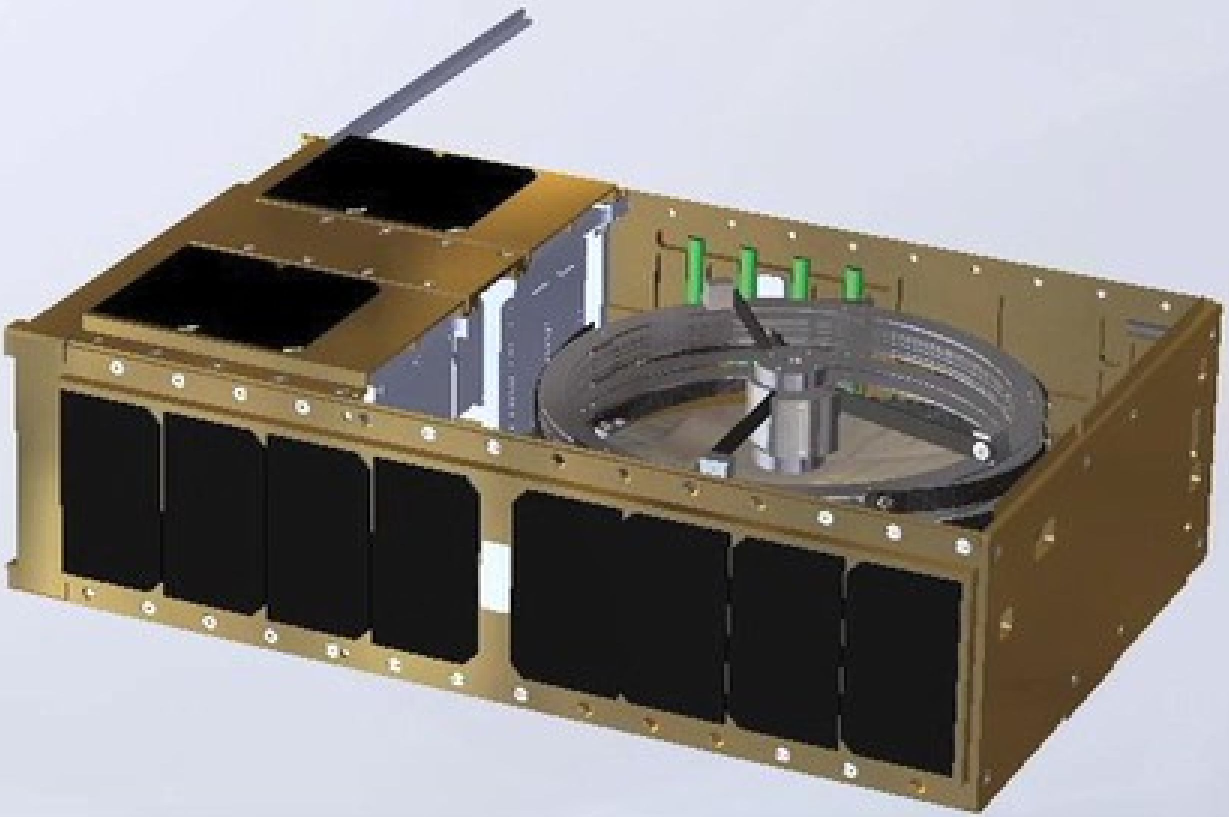
A. Rademacher, NASA-Ames



Design to fit within a 6u nanosatilite architecture

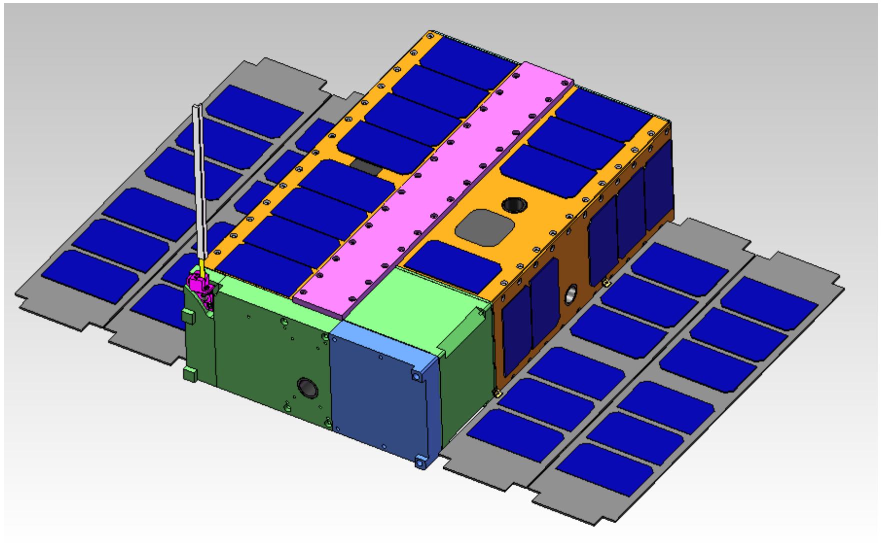
- 6in, f8 Telescope
- 1250mm focal length





HyCube: Hyperspectral Imager for Coastal Ocean Color

(A. Ricco, NASA-Ames)



CONFIGURATION: 6U Small Satellite

Bus: 1U, ADCS: 1.5 U

HyperSpectral Imager: 2U; Processor: 1U

Jettisonable drag kite: .5U

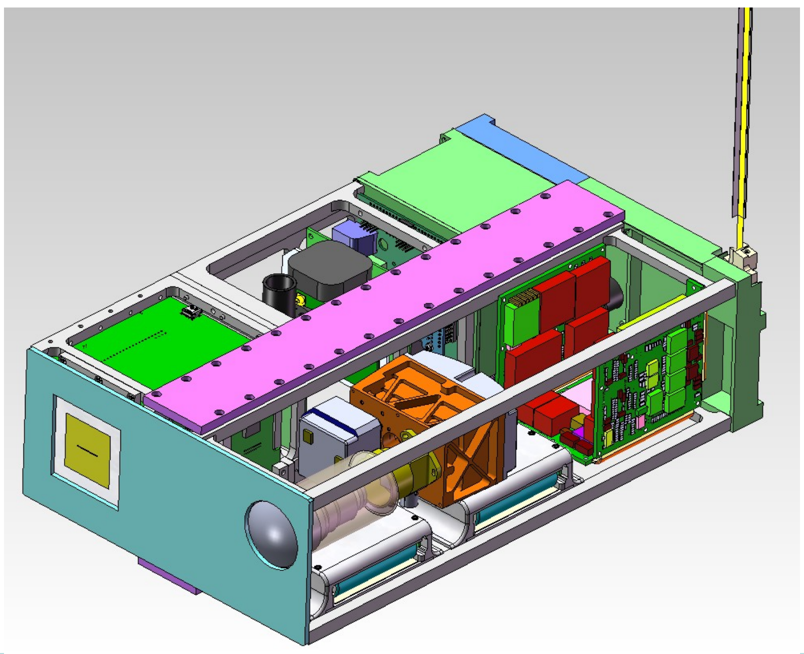
Key capability demos. in a small sat:

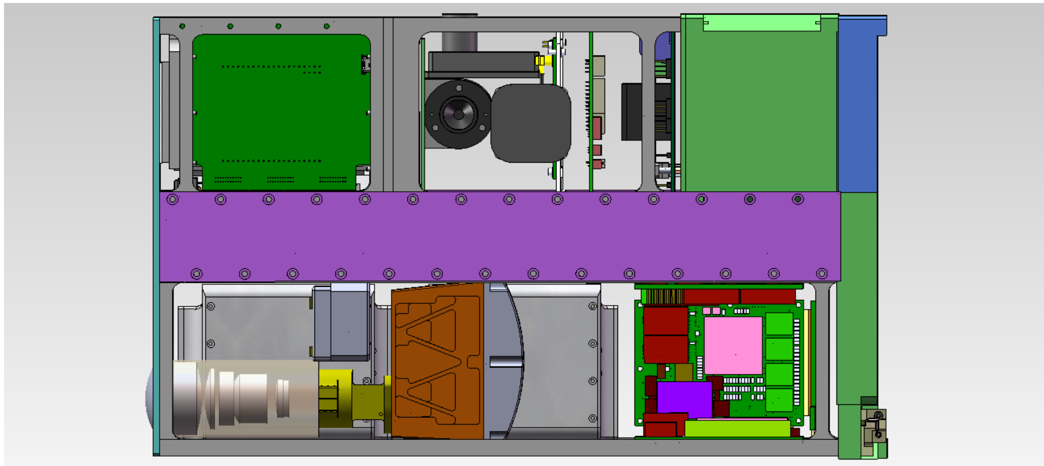
•High-performance ADCS for science: Earth imaging & astronomy

•"Large sat" data processing in a 6U

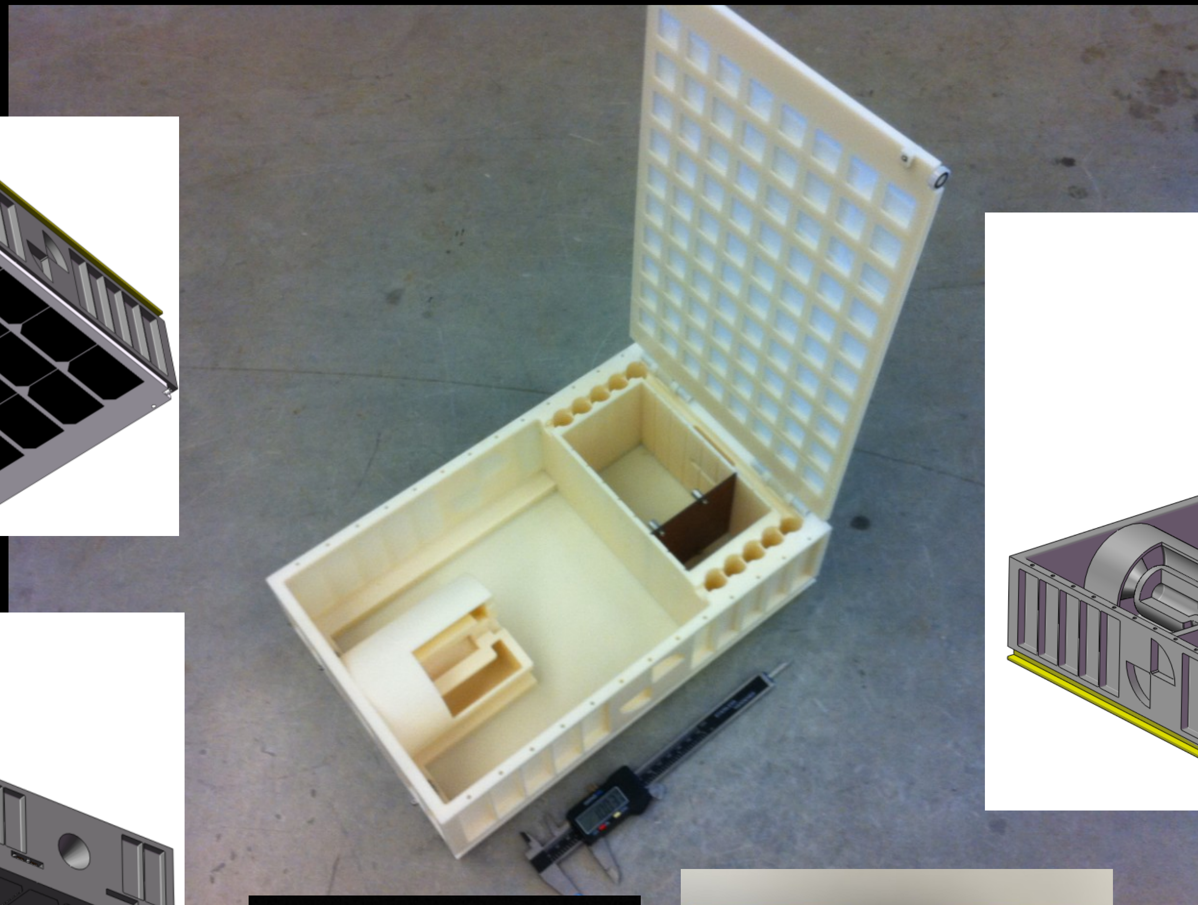
•10x - 100x data volume thruput improvement

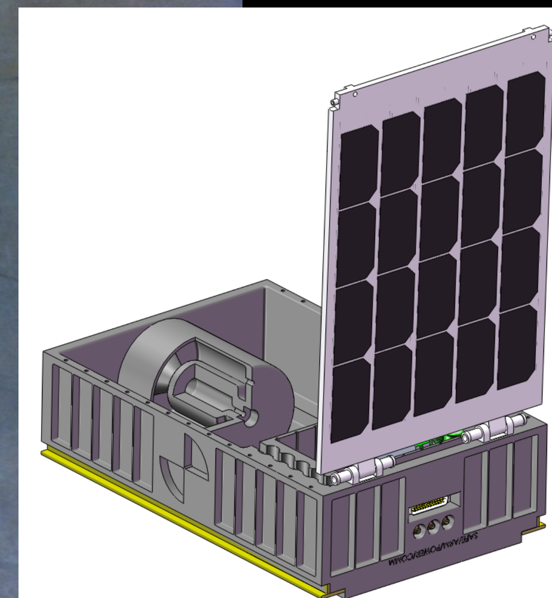
•Formation flying: single launch, multiple orbits

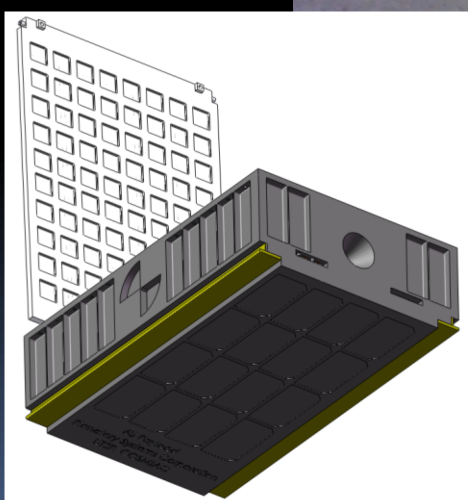


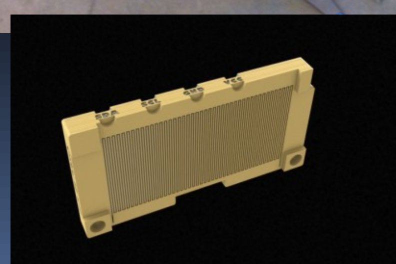


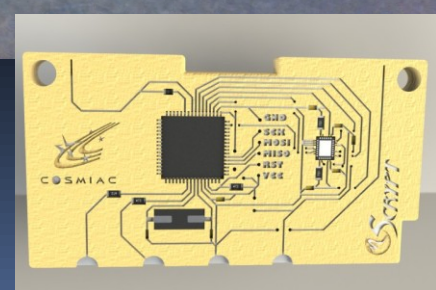
AFRL-COSMIAC 6U+ (3D printed)

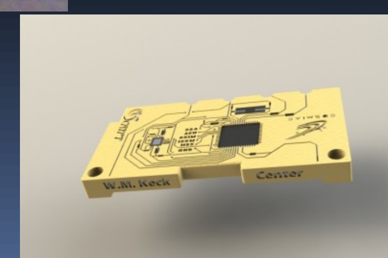


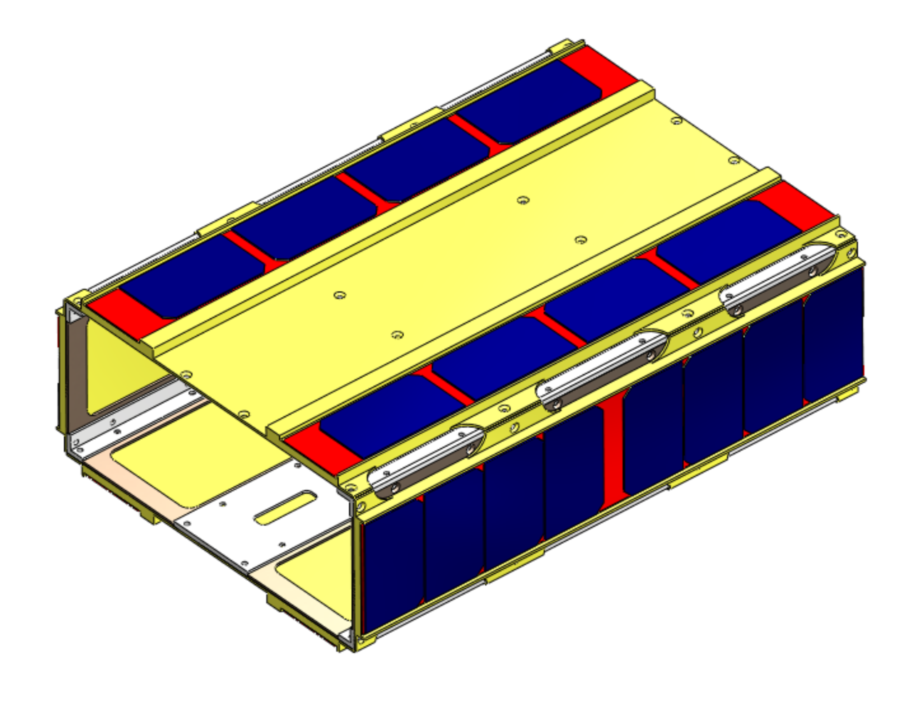
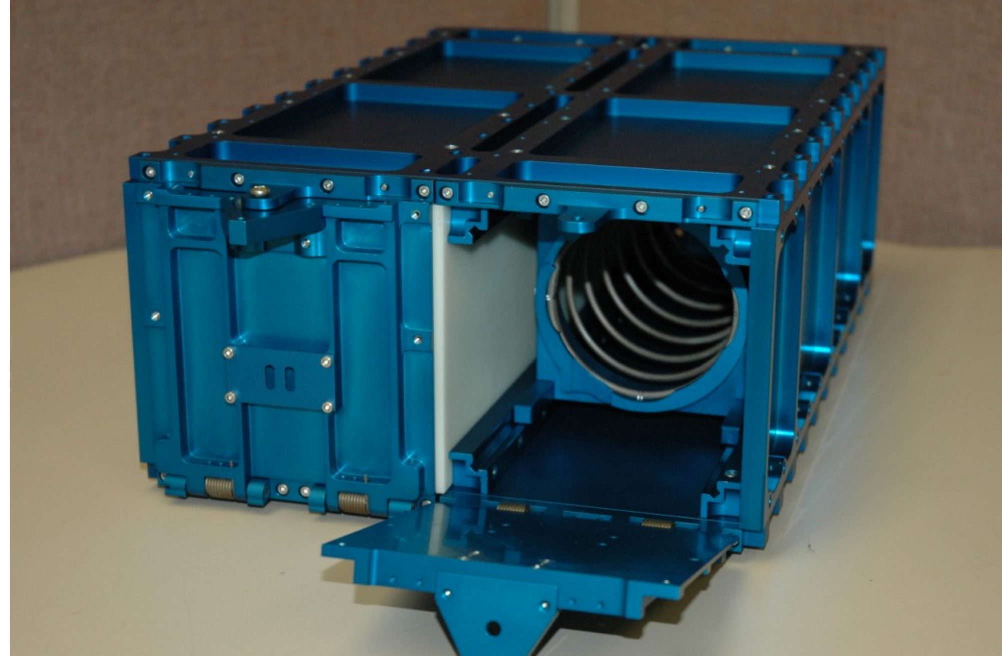
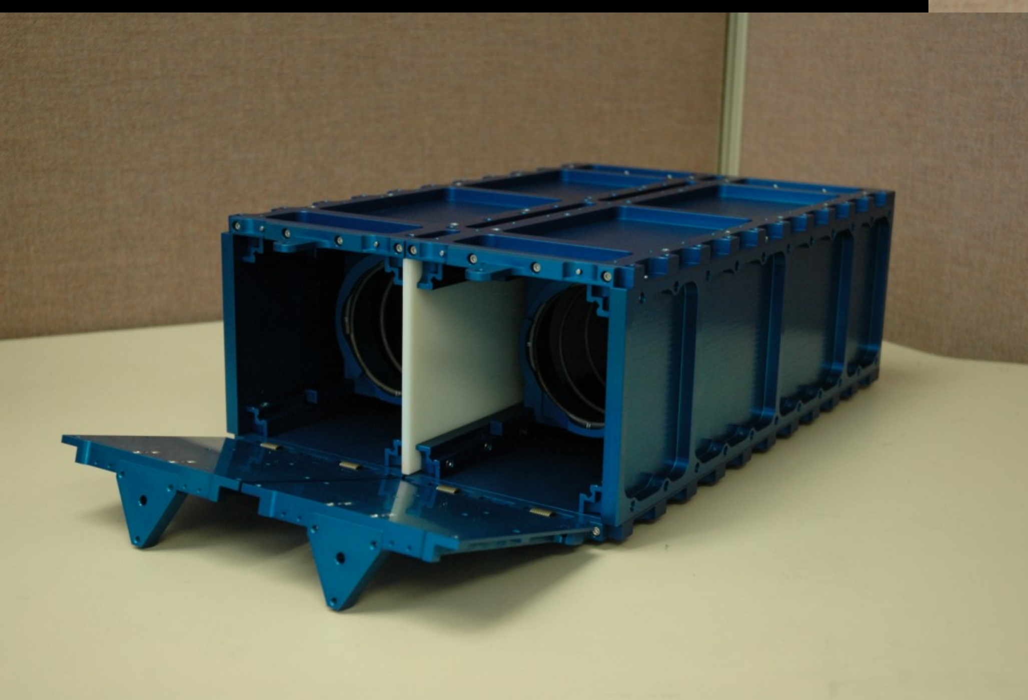




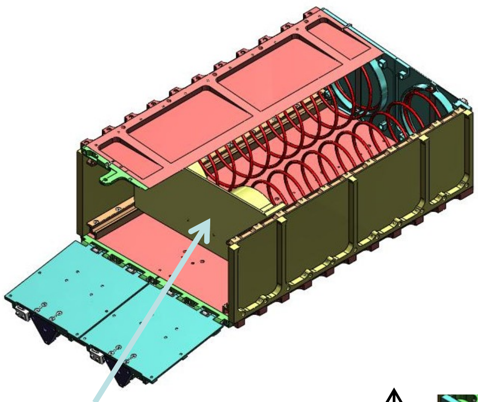


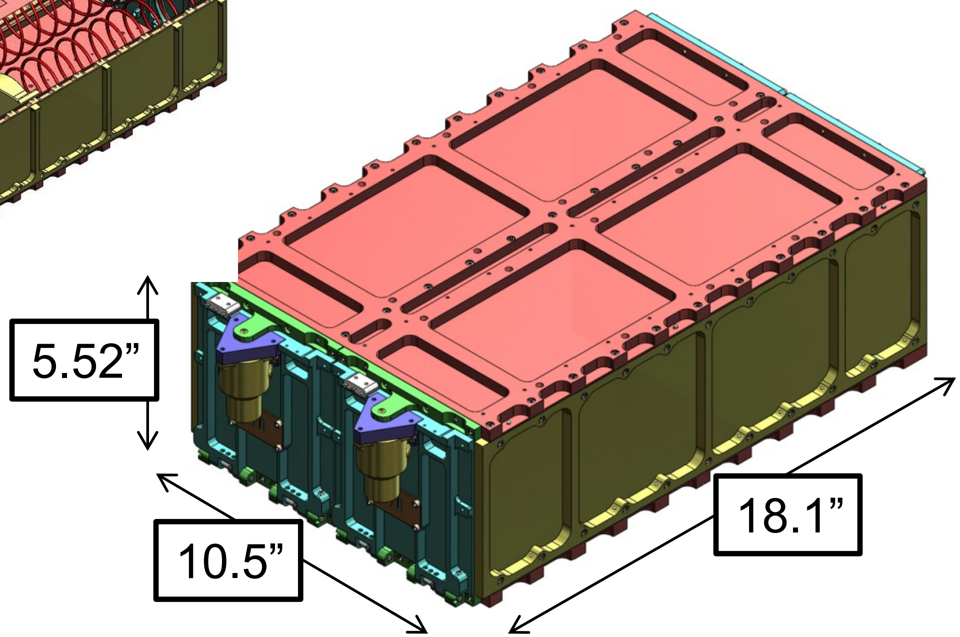


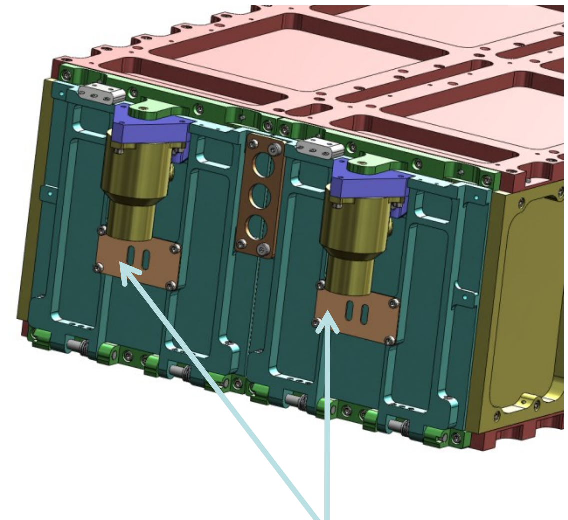


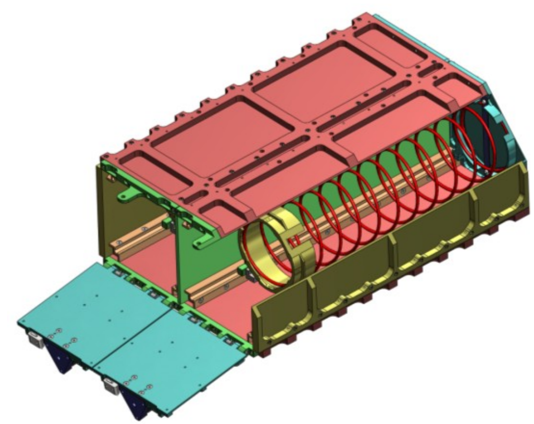





ARC 6U+ Dispenser







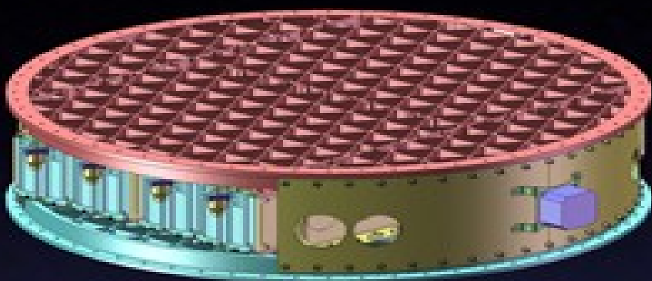


- 3U Or 6U Dispenser
- Modular Construction
- Similar Architecture/Philosophy as PPOD
- Mounts Identically as Two 3U PPODs Side by Side
- Dispenser Satellite Release Velocity Range: 1.18 M/S –2.03 M/S

National Aeronautics and Space Administration

Wafer NanoSatellite Rideshare Adapter

NASA - Ames Research Center

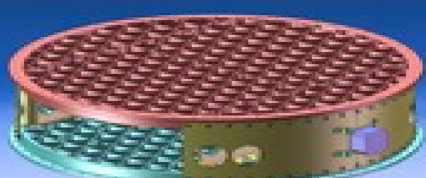


Description

- Fully functional, integrated, deployment system
- Supports multiple NanoSats, up to 50kg total mass
- Accommodates 450kg primary spacecraft
- Compatible with Falcon 1/1E and Minotaur 1
- Standard 38.81 inch Lightband interface

- The Wafer adapter is designed to safely deploy multiple spacecraft per launch
- Flexibility in design allows for easy expansion to multiple configurations

Reconfigurable, Non Load-Bearing Dispensers



Adapter

NanoSatellite

Four Reconfigurable Dispensers

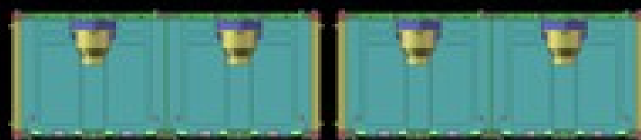
Two NanoSats or a SixPack

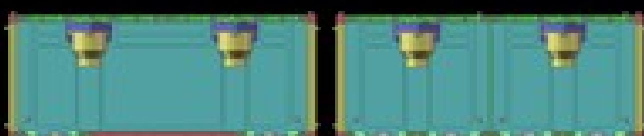
Advantages

- Potential rapid, standardized space access
- Reduced cost of spacecraft per mission
- Enhanced ability to carry additional payloads
- Increased payload sophistication and efficiency
- CubeSat compatible

Wafer Dispenser Configurations

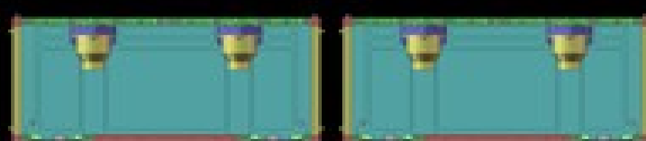
- Four NanoSat spacecraft
- One NanoSat equals ≈ 10 x 10 x 30 cm

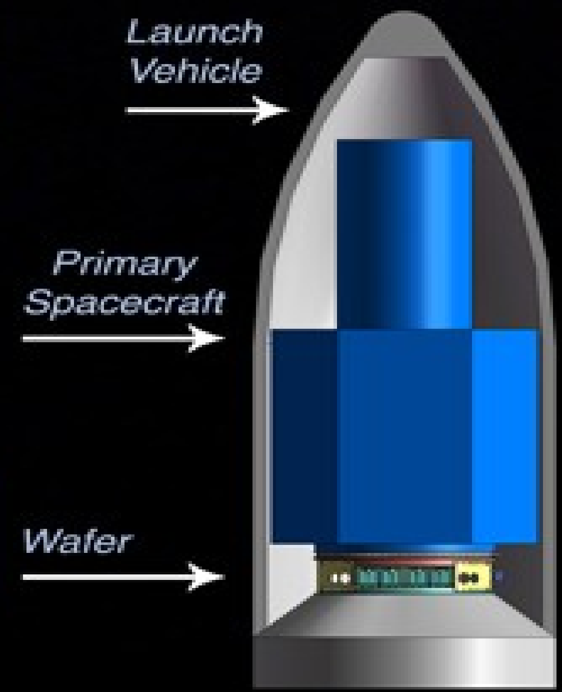




- One SixPack and Two NanoSat spacecraft
- One SixPack equals ≈ 10 x 23 x 30 cm

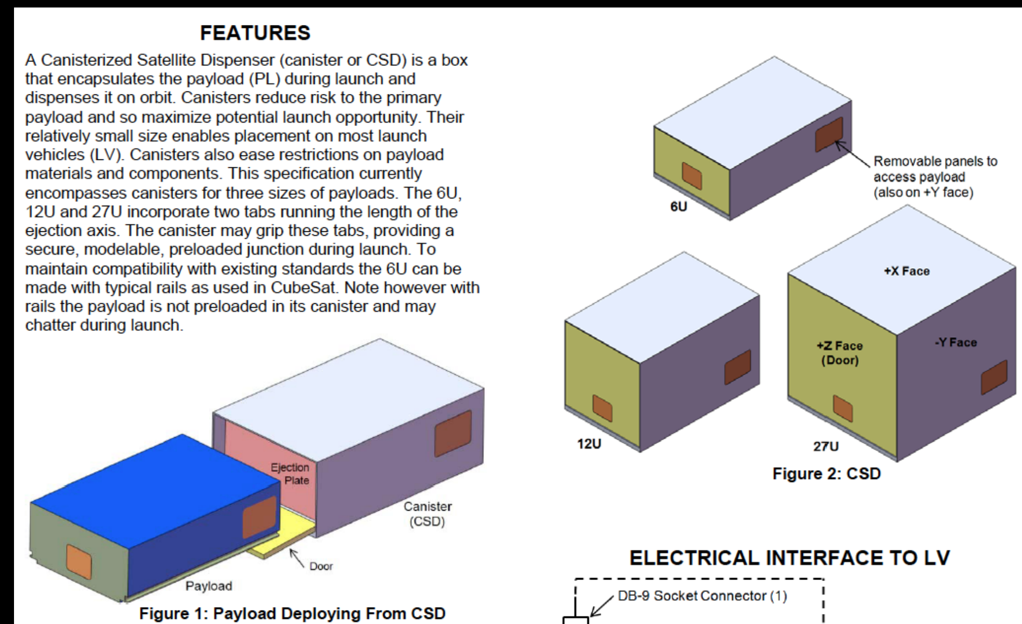
- Two SixPack spacecraft
- Each SixPack equals ≈ 10 x 23 x 30 cm





- Maximum 2.0 kg per cube equivalent
- Triple cube equivalent baseline designated as 1N
- Configurations of 1N (NanoSat) & 2N (SixPack)

Commercially Available 6U+ Dispensers



FEATURES

A Canisterized Satellite Dispenser (canister or CSD) is a box that encapsulates the payload (PL) during launch and dispenses it on orbit. Canisters reduce risk to the primary payload and so maximize potential launch opportunity. Their relatively small size enables placement on most launch vehicles (LV). Canisters also ease restrictions on payload materials and components. This specification currently encompasses canisters for three sizes of payloads. The 6U, 12U and 27U incorporate two tabs running the length of the ejection axis. The canister may grip these tabs, providing a secure, modelable, preloaded junction during launch. To maintain compatibility with existing standards the 6U can be made with typical rails as used in CubeSat. Note however with rails the payload is not preloaded in its canister and may chatter during launch.

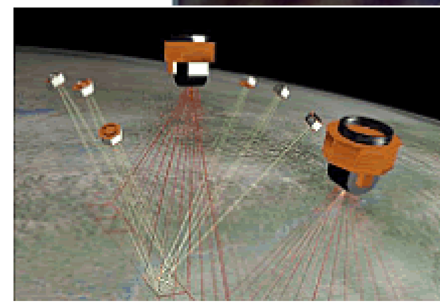
Figure 1: Payload Deploying From CSD

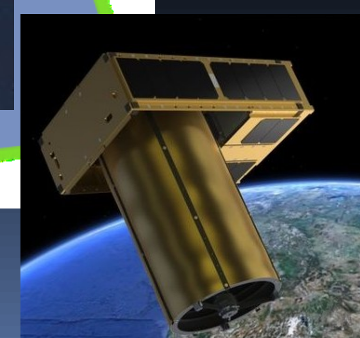
Figure 2: CSD

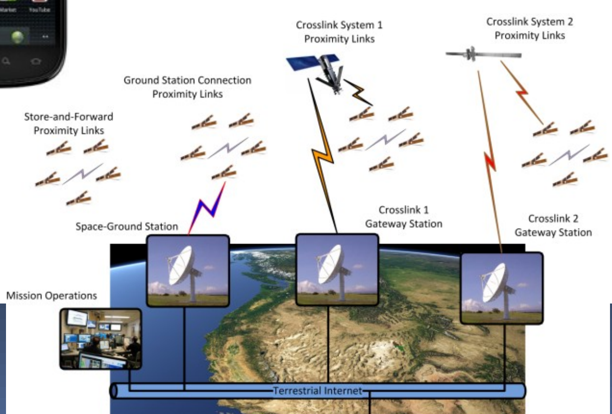
ELECTRICAL INTERFACE TO LV

CubeSatShop.com

Planetary Systems Corporation



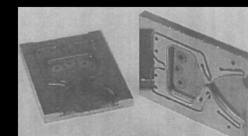



Crosslink System 1
Proximity Links
Crosslink System 2
Proximity Links
Ground Station Connection
Proximity Links
Store-and-Forward
Proximity Links
Space-Ground Station
Crosslink 1
Gateway Station
Crosslink 2
Gateway Station
Mission Operations
Terrestrial Internet

Spacecraft Technologies

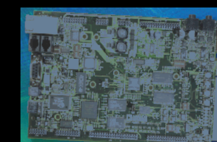
- Advanced Bus Architectures
  - Plug and Play
  - Autonomous Operations
- Data Handling
- Communications
- Guidance, Navigation and Control
  - MEMS Accelerometers and Gyroscopes
  - Miniaturized GPS Devices
  - Propellantless Attitude Control
- Multisatellite Operations
  - Formation Flying/Constellations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


Nano-ACS Thrusters


Micro-Propulsion


High Capacity, Lightweight Batteries

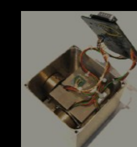

GPS Receiver


High Performance, Low Power Computing


5.8 GHz Transceiver


Sun Sensor


Mini Star Tracker


Nano Reaction Wheels

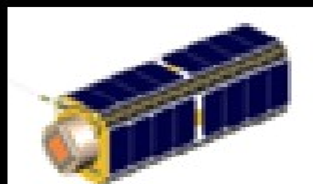

Ultra light weight IMU

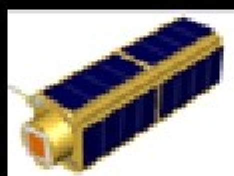
Enables a Variety of Science Missions:

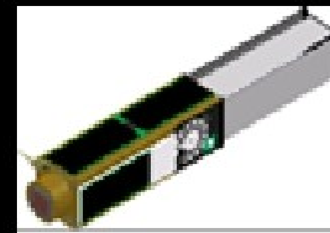
Precision Formation Flying
Remote Imaging- Earth/Lunar Science
Autonomous Satellite Maintenance
Space Physics & Astrophysics
Exploration- Lunar, NEOs, Comets

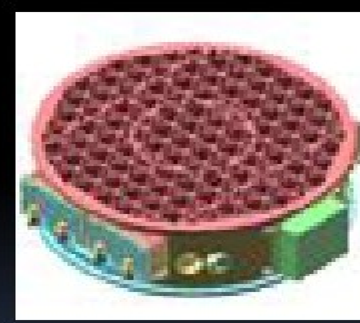
Nanosatellite Mission Heritage

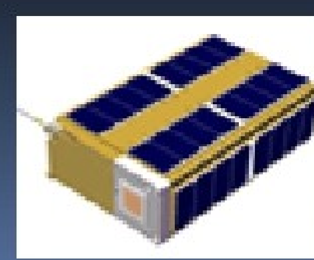
GeneBox



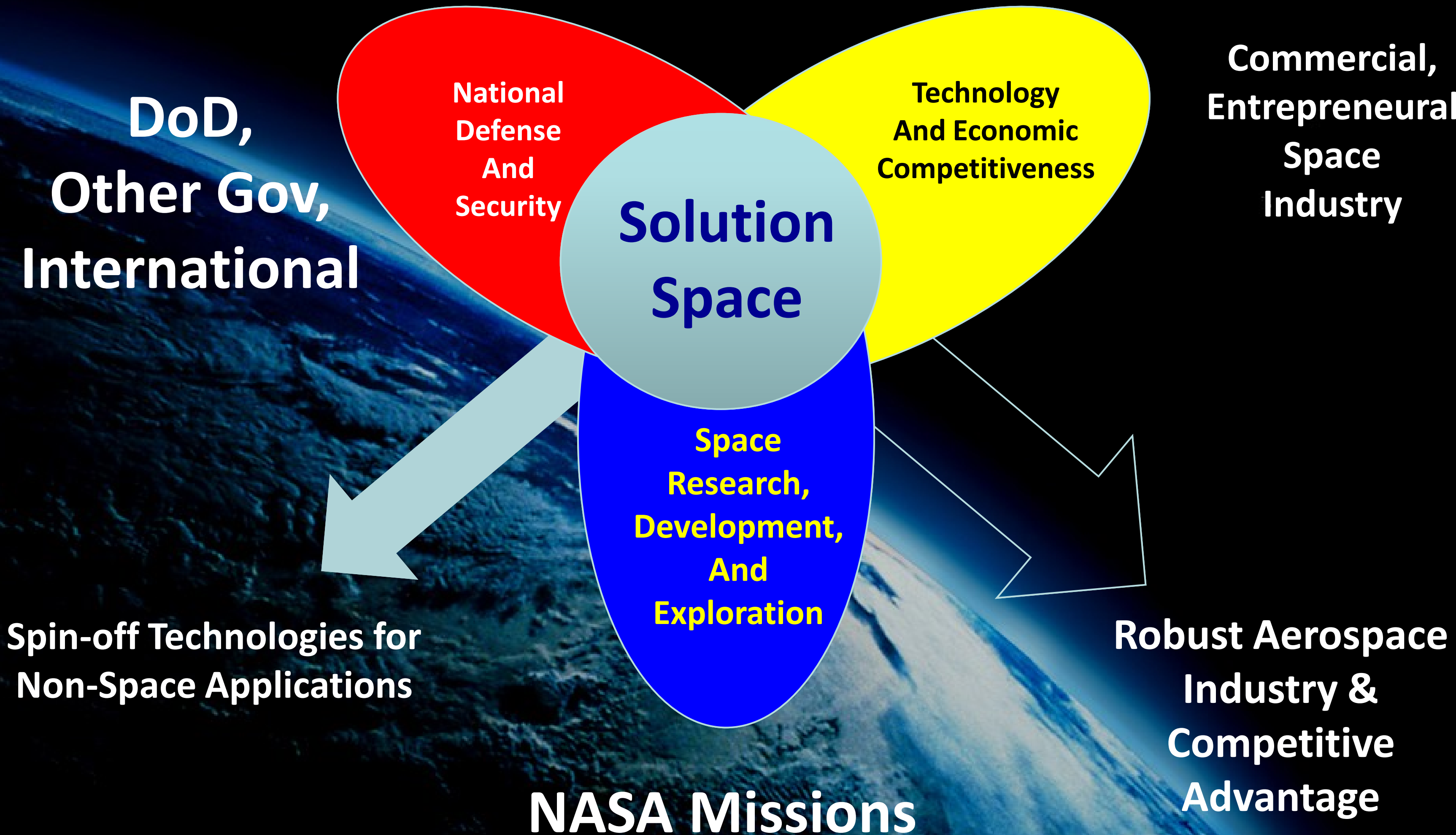








Technology and Innovation Strategy
… Addressing Global Needs



ARC Strategic Technology Initiatives 2012

Active Initiatives

1. Biological Technologies for Life Beyond Low Earth Orbit (BT4LBLEO)
2. **Small Spacecraft and Missions Enterprise (SSME)**
3. Science Instruments for Small Missions (SISM)
4. Advanced Digital Materials and Manufacturing for Space (ADMMS)
5. Designing High-Confidence Software and Systems (DHCSS)
6. Cyber-Physical Systems Modeling and Analysis (CPSMA)

Other Suggested Initiatives

1. First Responder, Emergency, and Diasaster Assistance (FREDA)
2. Emerging Aeronautics Systems and Technologies (EAST)
3. GREEN Technologies (Technologies for Sustainability)

National Aeronautics and Space Administration

www.nasa.gov

Cubesats: Biological Missions

- Gene-Sat 1
- Pharmasat-1
- O/OREOS