NASA Ames SmallSat and Nanosats

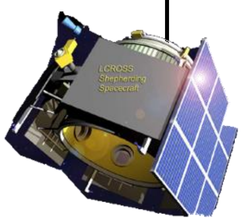
March 2015

Roger Hunter
Associate Director, Programs & Projects
NASA Ames Research Center

Ames' Small Spacecraft Timeline

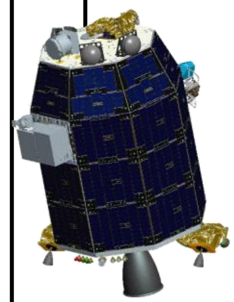
2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018+

Lunar Missions

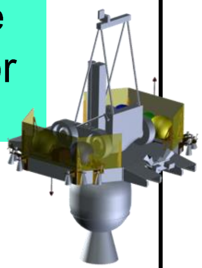


LCROSS (ESMD)

LADEE (SMD)

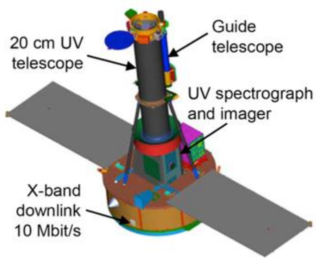


Resource Prospector (HEOMD)

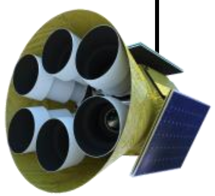


Earth Orbital

IRIS (LMCO/SMD)



TESS (GSFC/SMD)



= Launched

= In development

NASA Ames develops capable, cost efficient (< $250M) Small Satellites

LCROSS Lunar Impactor - 2009

Risk Position: Class D, Secondary Payload to LRO

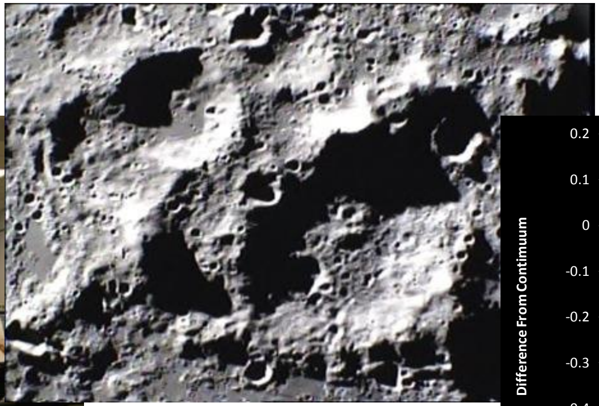
Cost-Capped: $79M cost cap (including margin)

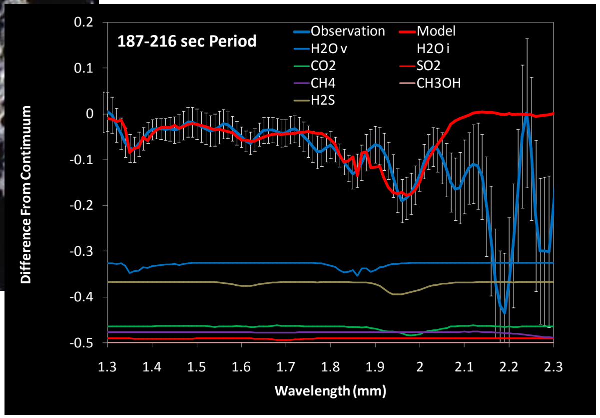
LV Mass-limited: 1000kg *(including adaptor)*

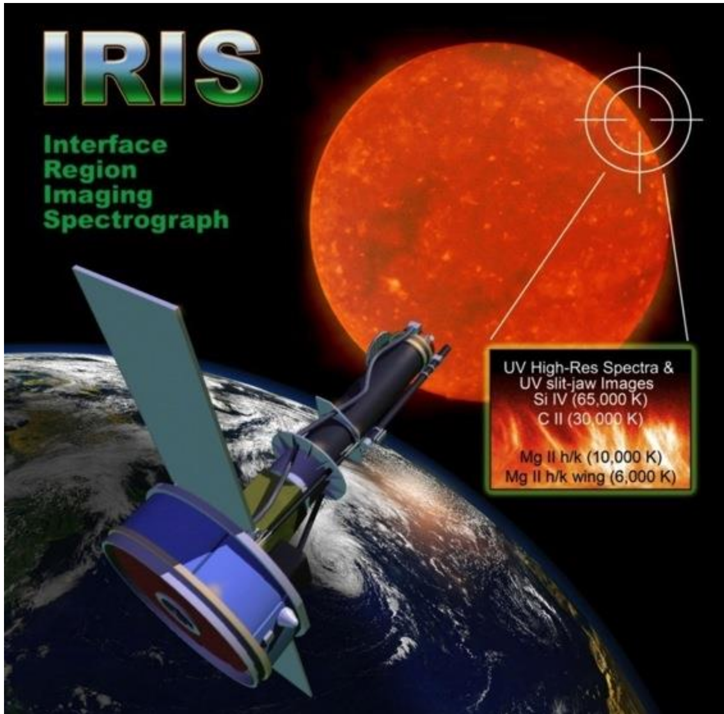
Schedule-Constrained: 30-month development (Phases A-D)

LAUNCHED ON-TIME AND ON BUDGET

Result: <u>Found significant Water on the Moon, and Changed the our understanding of Volatiles on the lunar surface</u>.







IRIS:

Interface Region Imaging Spectrograph

Mission Type: SMEX, Heliophysics, $105M cap, GSFC Program Office, Launched in 2013

Ames Roles/Responsibilities:

Assistant Project Manager, Science Co-I
Systems Engineering, EPO Support
Main role: Spacecraft Mission Operations

SCIENCE OBJECTIVES

- Which types of non-thermal energy dominate in the chromosphere and beyond?
- How does the chromosphere regulate mass and energy supply to the corona and heliosphere?
- How do magnetic flux and matter within it rise through the solar atmosphere and what role does flux emergence play in flares and mass ejections?

“A SMall EXplorer mission to understand how the solar atmosphere is energized”

Leads http://iris.lmsal.com/

Principal Investigator (LMSAL)	Alan Title
Science Lead (LMSAL)	James Lemen
Project Manager (LMSAL)	Gary Kushner
Assistant Project Manager (ARC)	John Marmie

LADEE : Lunar Atmosphere and Dust Environment Explorer

Objective

- Measure the Lunar Dust
- Examine the Lunar atmosphere

Key parameters

- Launched Sept 6, 2013
- Impacted on April 18th, 2014

Spacecraft

- Type: Small Orbiter - Category II, Enhanced Class D
- Provider: NASA ARC and NASA GSFC

Instruments

- Science Instruments: NMS, UVS, and LDEX
- Technology Payload: Lunar Laser Communications Demo

Launch Vehicle: Minotaur V

Launch Site: Wallops Flight Facility


Ben Cooper / LaunchPhotography.com

LADEE Mission Success

Launched on Sept 6, 2013

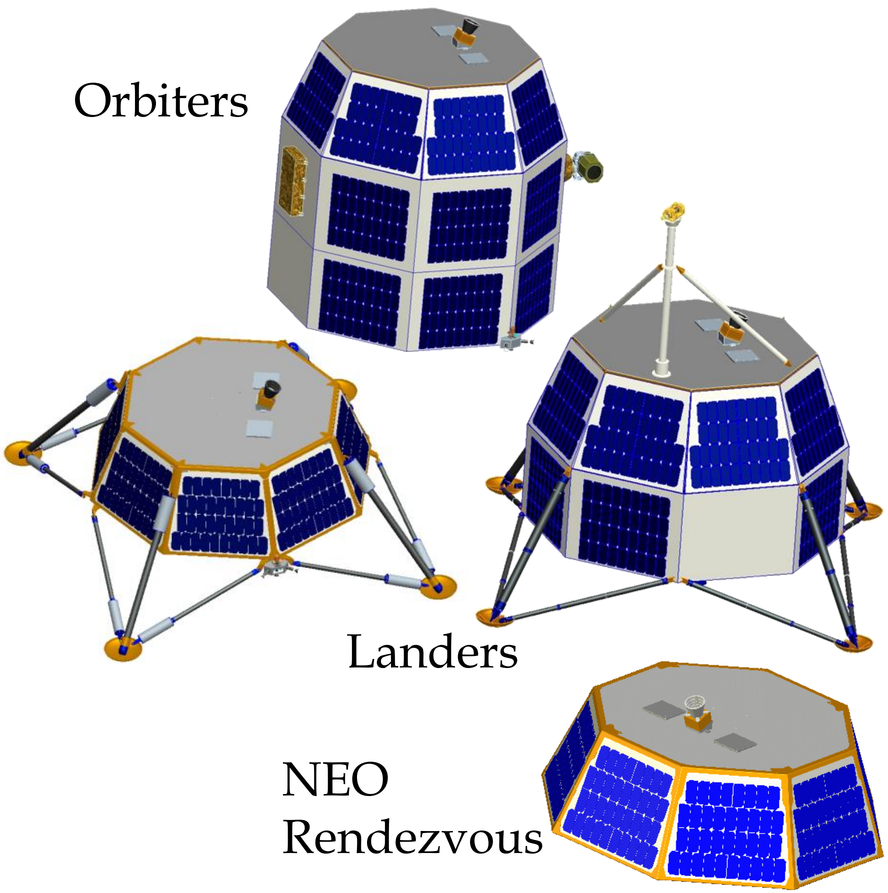
In Lunar Orbit on Oct 6, 2013

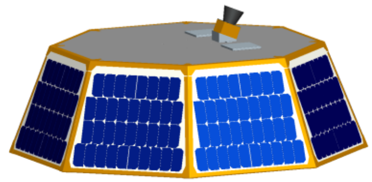
Met Level 1 Milestones, operated over 140 days

Operated out of the Ames MMOC in N240

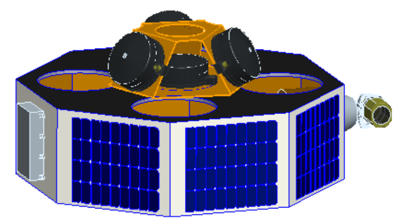
Impacted on the Lunar Farside on April 17, 2014

Ames Common Spacecraft Bus – Modular Approach

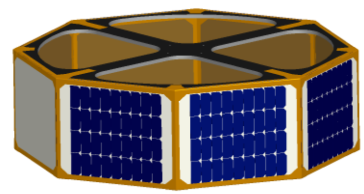




- Bus Module

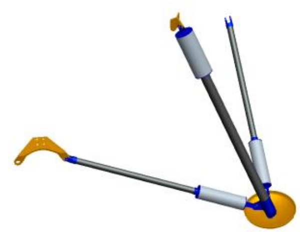


- Payload Module



- Extension Module

- Propulsion Module



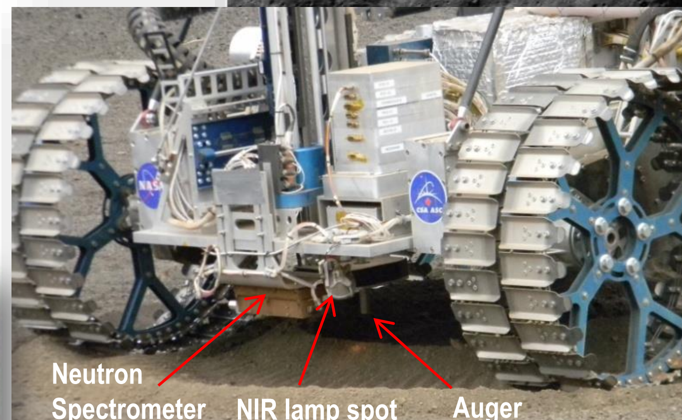
- Legs

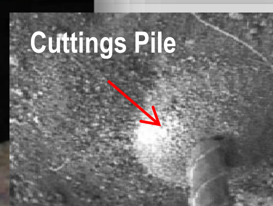
Multi-Mission Capability enabled by Modular Bus Design – Select Modules to meet Mission Requirements

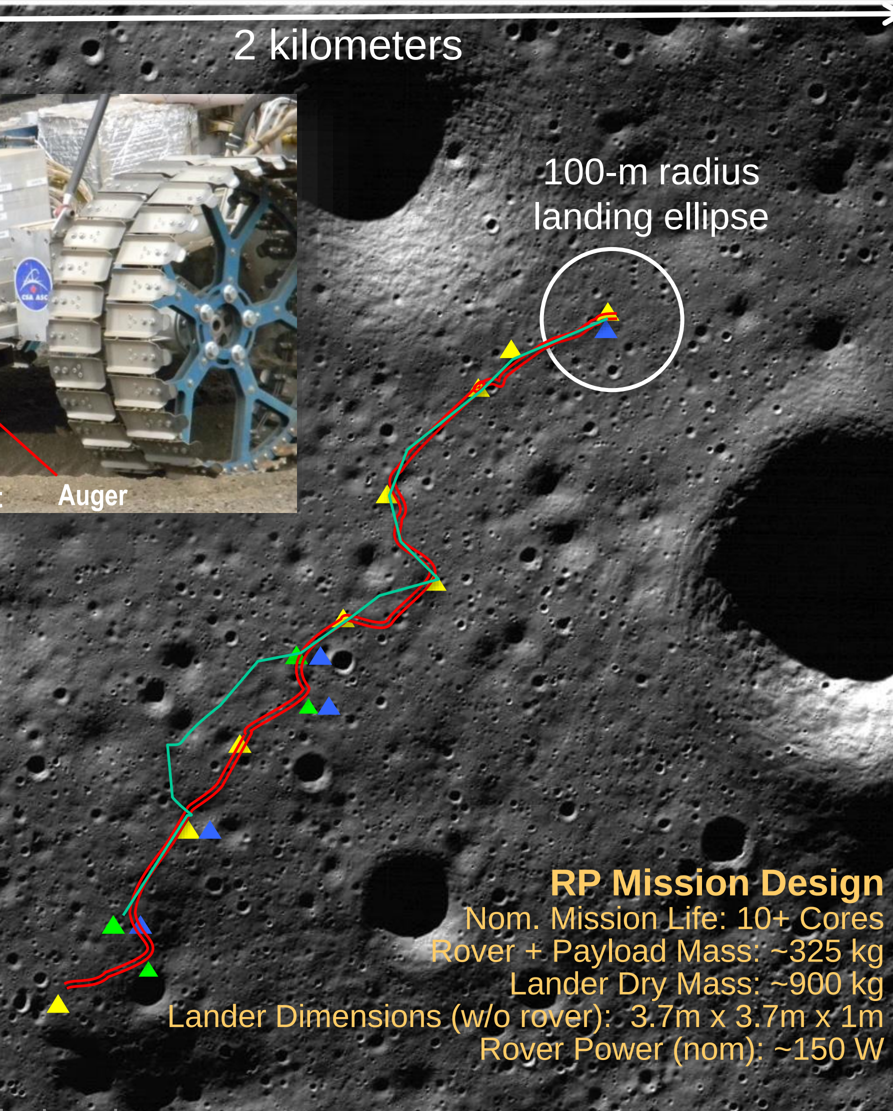
Resource Prospector (RP) Mission - 2020

Mission:

- Characterize the constituents and distribution of water/volatiles in lunar polar surface materials
- Demonstrate ISRU oxygen extraction from lunar regolith
- NASA ARC, KSC, JSC, MSFC







RP Mission Design
Nom. Mission Life: 10+ Cores
Rover + Payload Mass: ~325 kg
Lander Dry Mass: ~900 kg
Lander Dimensions (w/o rover): 3.7m x 3.7m x 1m
Rover Power (nom): ~150 W

RPM Flight Project Office (NASA-ARC)

- ✓ FY13: Pre-Phase A: MCR (Pre-Formulation)
- FY14-15: Phase A (Formulation)
- FY16: Phase B: SRR, PDR (Prelim Design)
- CY19: RPM launch
- $250M LCCE Cost Cap, HEOMD
- Class D, Category 3 (<$250M)
- LV: Falcon 9 v1.1 class

Smallsat Missions are a Disruptive change…

SMALL SATELLITES

More With Less

Small satellites gaining users as capability and applications increase

Frank Morring, Jr. Washington

Small satellites, once the realm of one-off low-budget science missions and undergraduate engineering classes, have come full circle with the growing realization among hard-pressed, high-end users that the little birds can do the big jobs, too.

The smallest of them—cubesats—are rapidly evolving into an operational commercial, scientific and military technology. Higher up the payload-weight scale, the high cost per pound of launching payloads and the growing skill of spacecraft miniaturizers are making satellites that are small enough to ride as secondary payloads attractive to a variety of customers, particularly if they can be mass-produced or produced rapidly in single units.

The launch-cost consideration may change, as the growing interest in small spacecraft attracts a new generation of small launchers designed to carry them. And the spacecraft themselves are increasingly capable, with government money flowing into the arena in search of a way to do more with less.

"From where we have been 10 years ago to where we are now is a complete 180," says Roland Coelho, a member of the research staff at California Polytechnic State University's engineering school, one of the main U.S. centers for cubesat development. "In the past it's been primarily educational. . . . As we have kind of grown—the entire community worldwide over the past decade—we really have started to see some niche markets where cubesats can play a vital role. It's clearly the most evident in the government cubesat programs that we have today. The government, and particularly the U.S. government, has been the driving force in this technology because that's where all the funding is."

Government interest in small satellites is not limited to cubesats, or even to spacecraft. The U.S. Defense Advanced Research Projects Agency (Darpa) is spending $46 million to find ways to launch satellites weighing up to 100 lb. on 24-hr. notice for less than $1 million (see p. 44). And the Air Force and National Reconnaissance Office consider small satellites a way to lower risk in national security spacecraft by adding redundancy in orbit.

"Even if 20% of them failed, you'd still do your mission, so there's sort of a natural resiliency in using constellations of smaller satellites," says John Roth, whose company—Sierra Nevada

AviationWeek.com/awst

TechEdSat is scheduled to be the first U.S. cubesat deployed from the International Space Station.

For additional photos and the latest on smallsats, check out the digital edition of AW&ST on leading tablets and smartphones, or go to AviationWeek.com/smallsats

36 AVIATION WEEK & SPACE TECHNOLOGY/JULY 30, 2012

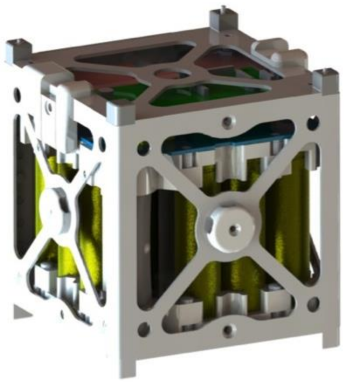
NASA Ames' TechEdSat Mission, Launched in June 2012, Deployed from ISS on Oct 4

Cubesats (aka Nanosats)

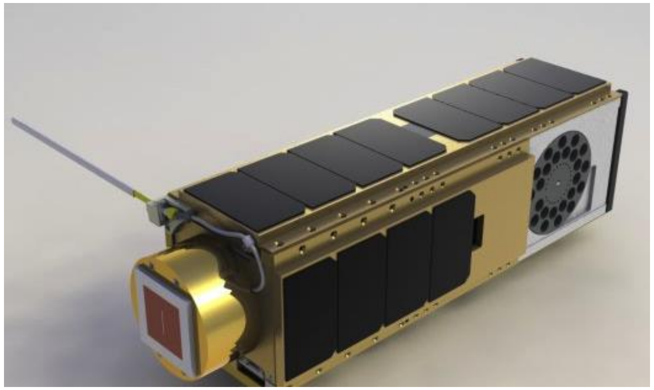
- Started as a University standard for teaching satellite design
  - Cal Poly University and Stanford University
- 10 X 10 X 10cm Cube as a Standard form factor = 1U
- Weighing 1-1.5 kgs for each 1U of volume

Common Form Factors

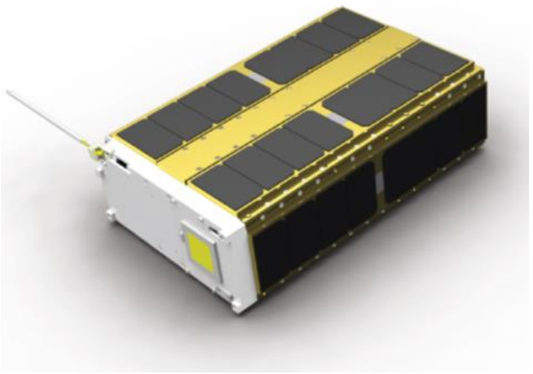
1U



3U



6U



Nanosat's Value Proposition: High ROI

Mission Concepts to space mission Results in 18-24 months

- Frequent access to space
- Ability to execute rapid response missions
- Ability to perform many aspects of a NASA mission
- Comparatively low-cost missions
- Reflight of <u>same</u> hardware in 9-12 months

Ames Nanosat Missions

Ames Nanosats support the goal of:

- Space Biology science,
- Technology Demonstrators, and
- EDL and Downmass investigations.

Ames:

- Achieved peer-review Science with its Nanosat Missions.
- Deployed NASA's first 1U and 3U Nanosats from ISS
- Deploying the first Nanosat Swarms in-space
- Developing the first Beyond LEO Bio-nanosat (Biosentinal)

Nanosat Missions

2006 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

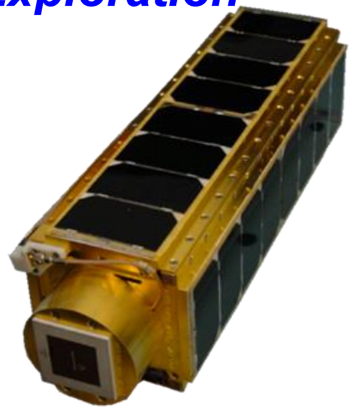
- **GeneSat** 3U s/c
- **PreSat*** 3U s/c
- **NanoSail-D1*** 3U s/c
- **PharmaSat** 3U s/c
- **O/OREOS** 3U s/c
- **NanoSail-D2** 3U s/c
- **PhoneSat1ß** 1U – SubOrbital Test
- **TechEdSat1** 1U s/c
- **PhoneSat 1 & 2ß** (3) X 1U s/c
- **PhoneSat2.4** 1U s/c
- **TechEdSat3p** 3U s/c
- **PhoneSat2.5** 1U s/c
- **SporeSat1** 3U s/c
- **KickSat** 3U s/c (104) X ChipSats
- **TechEdSat4** 3U s/c
- **NODeS** (2) X 1.5U s/c
- **EDSN** (8) X 1.5U s/c
- **EcAMSat** 6U s/c
- **TechEdSat5** 3U s/c
- **SporeSat2** 3U s/c
- **BioSentinel** 6U s/c

= Launched
= In development
= Deploy from ISS
= Future mission in formulation

NASA Ames is leading the Agency in Cubesats.
ISS is a Critical Deployment platform

Space Biology Nanosats: *Testing Life in Space*

Validating, Enhancing and Extending ISS biological testing for Exploration

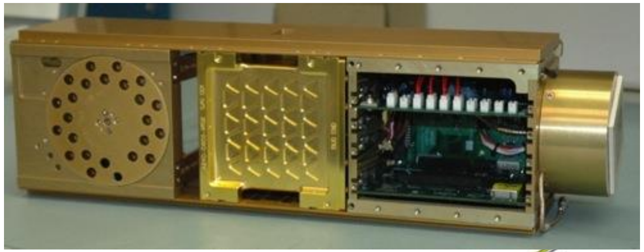


PharmaSat

- 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

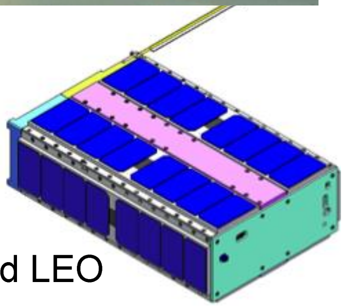


SporeSat 1 & SporeSat 2 (ISS deployed)

- 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 (The First Deep Space Bio Experiment)

- 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

BioSentinel deep-space Nanospacecraft

Mission Objectives:

A freeflyer Nanospacecraft launched as a secondary payload on EM-1

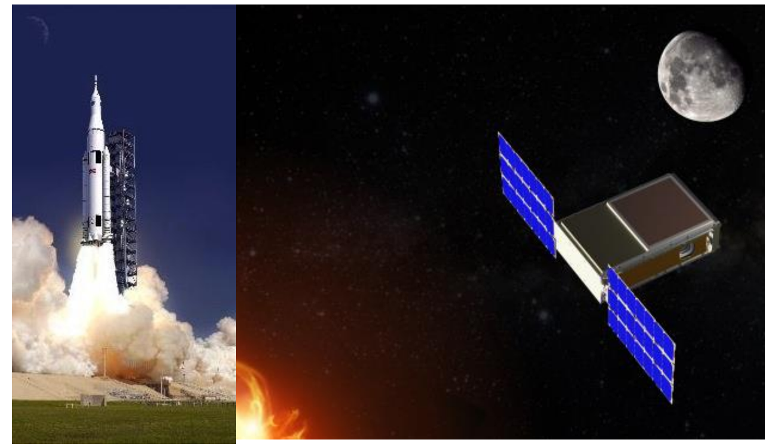
- Range to Earth of 0.73 AU at 18 months
- Far outside the protective shield of Earth's magnetosphere

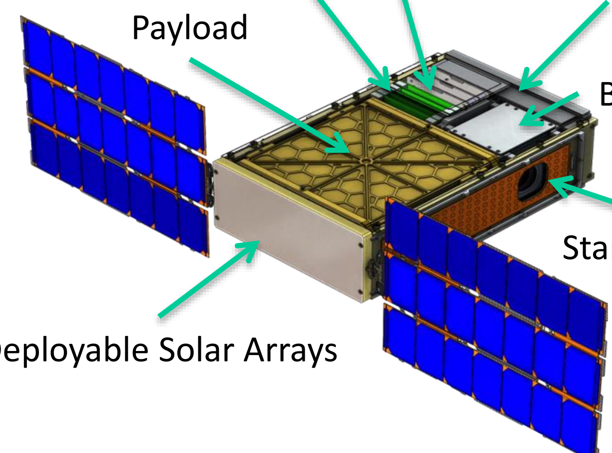
Conduct life science studies relevant to human exploration

- 1st biological study beyond LEO in over 40 years
- BioSentinel uses DNA double strand break frequencies to calibrate radiation damage in space
- Validate biological radiation damage models in space
- Demonstrate "biosentinel" science concept

Design payload with sensors for multiple environments

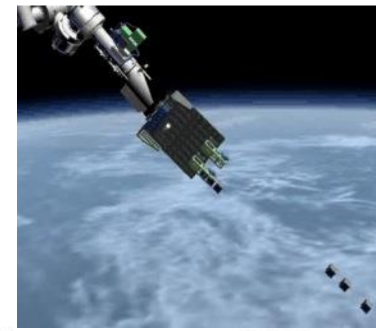
- BioSensor, LET Spectrometer, TID Dosimeter
- Instrument on ISS at similar time to EM-1 launch
- Ground controls in lab and at radiation beam facilities





TechEdSats: *Re-Entry Technology Demonstrators*

ISS Downmass and EDL demonstrators

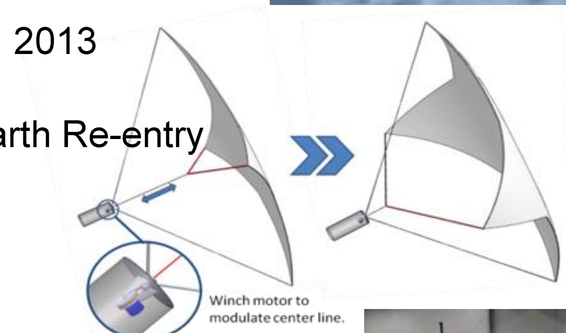


TechEdSat-1: First U.S. & NASA CubeSat launched from ISS

- 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; De-Orbit validation burned up during Earth Re-entry

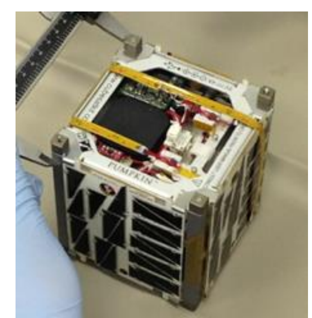


TechEdSat-4: Deploying from ISS Feb 2015

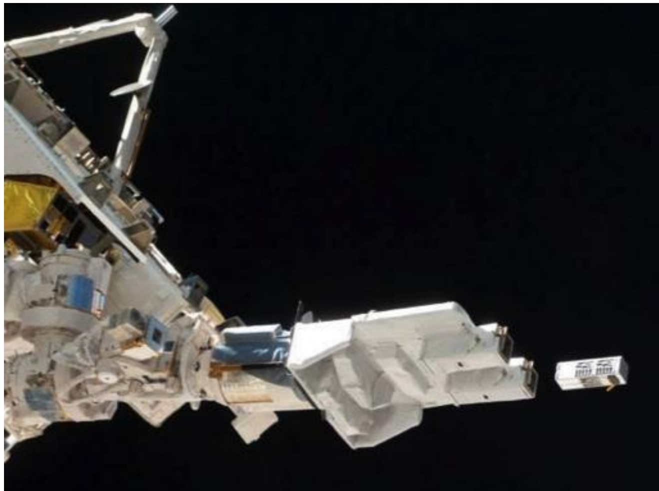
- 3U Nanosat, launched July 2014 on Orbital's Orb2 to ISS
- To be deployed from Nanoracks Cubesat Launch system
- Reflight of TechEdSat-3p Exobrake, updated Iridium & GPS hardware

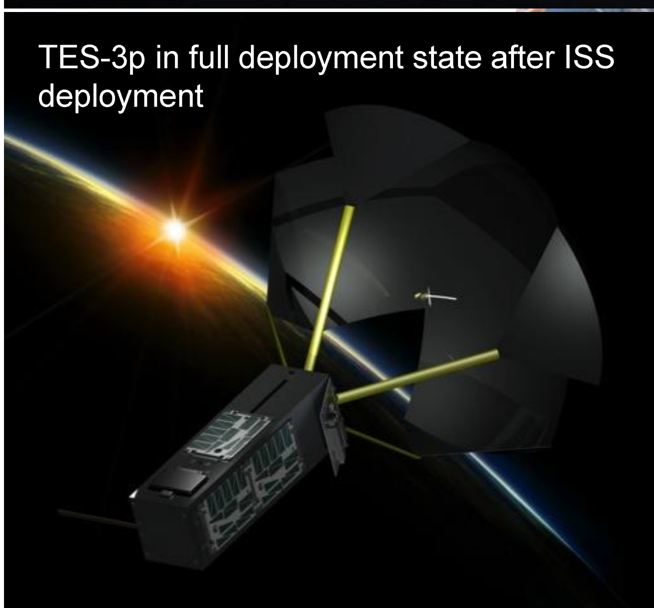
TechEdSat-5: Planned to deploy from ISS in late 2015

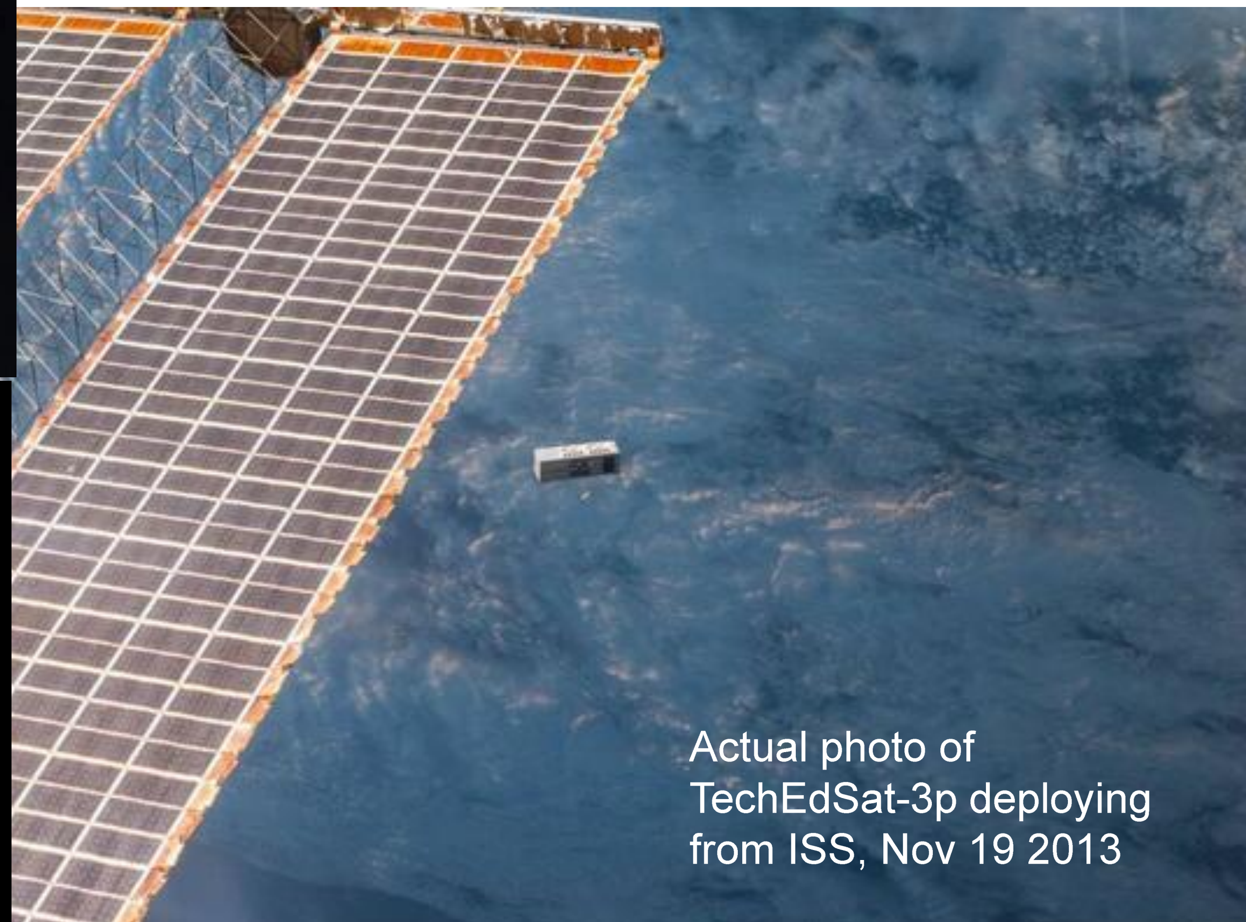
- 3U Nanosat, to be launched ~Mid 2015 to ISS
- First "Modulated" Exobrake to target re-entry point
- Updated Avionics, Radio, Iridium & GPS hardware



TechEdSat-3p Deployment Images

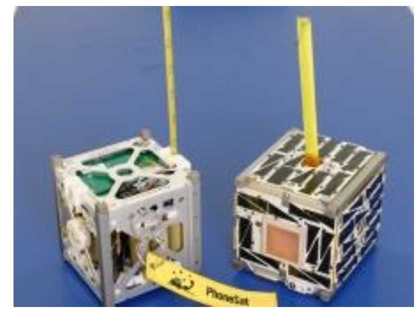



TES-3p in full deployment state after ISS deployment


Actual photo of TechEdSat-3p deploying from ISS, Nov 19 2013

PhoneSats/EDSNs: *COTS Tech Demonstrators*

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

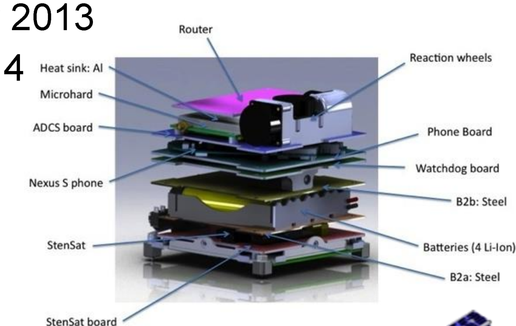


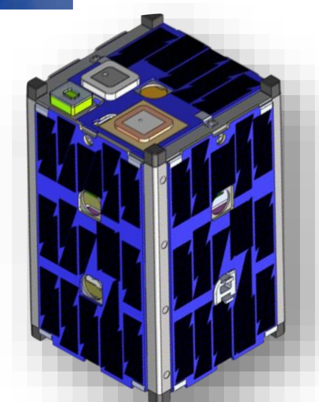
PhoneSat 1: First Phone-based spacecraft

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

PhoneSat(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





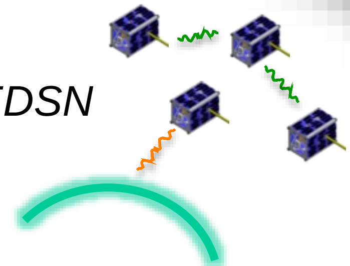
EDSN: First Nanosat Swarm

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

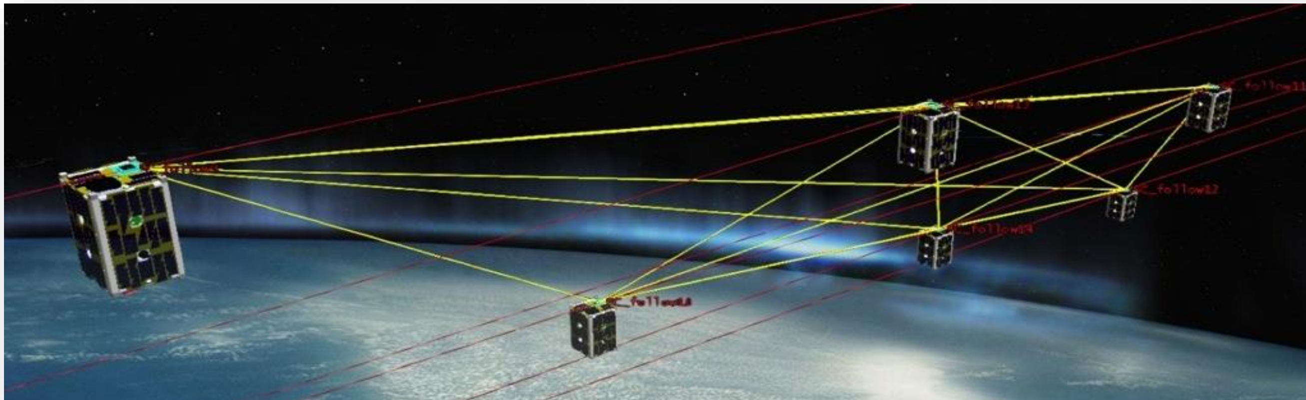
NODeS: ISS Nanosat Swarm demonstrator

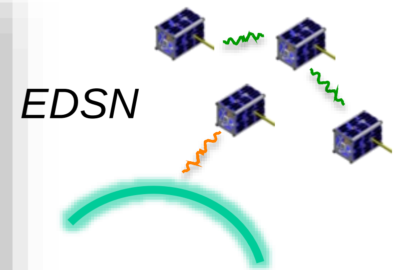
- 2 EDSN Nanosats with Advanced Software deploying off of ISS

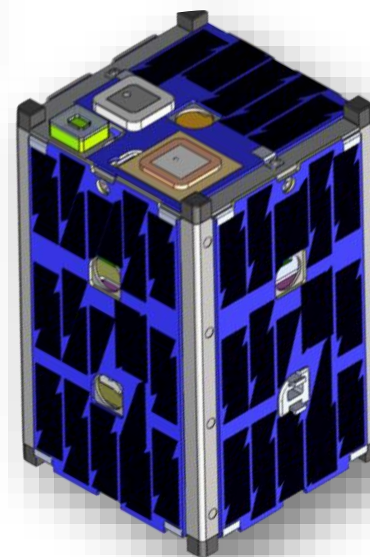
EDSN



EDSN: A Nanosat Swarm







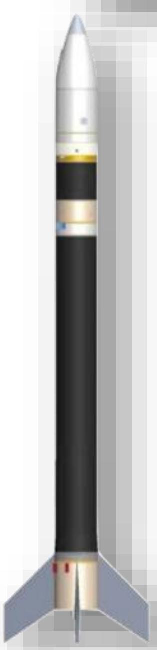
Small Spacecraft Technology Demonstration:

- **Novel intra-swarm communications**

  The first true Swarm in space. Configured to allow spacecraft to talk to each other and share data, while taking geographically dispersed payload measurements

  1 spacecraft talks to Ground for the whole Swarm.

- **Multi-point space physics (radiometers)**

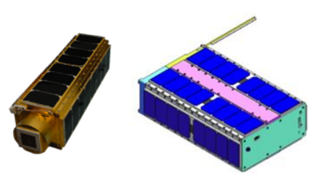
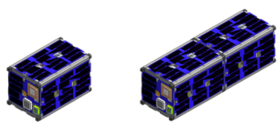
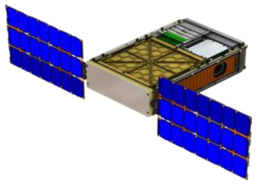


Fall 2014 Launch

- NASA Ames – PM and S/C bus
- Montana State University – Instrument
- Santa Clara University – Ground Station

EDSN spacecraft is a 8x 1.5U nanosat technology mission from NASA's Space Technology org

Nano-Spacecraft Bus	SporeSat Bus	EDSN/Nodes Bus	BioSentinal Bus
Flight Heritage	2006, 08, 09, 14, 15	Jan 2015, Feb 2015	Planning for 2017-18
Nominal Spacecraft Size	3U - 6U	1.5U -10x10x17cm up to 3U	6U
Bus Avionics	BioBus	Phonesat+	Sentinel Bus
Bus Volume	1U	1.25U	2U
Satellite Mass	4.5 - 7 kg	1.73 kg	~14 kg
Bus Mass	1.64 kg	1.68 kg	8 kg
Satellite Power	3.6 - 5.3 W Orbit Avg	1W Orbit Avg	15W Orbit Avg
Payload Power Available	5 - 10W	1 - 5W	6W+
Payload Volume	2U - 10x10x20cm	0.25U up to 1.5U - 10x10x15cm	4U - 10x20x20cm
Payload Mass	3 - 5 kg	0.05 - 3 kg	6 kg
Altitude	325 - 800km	400 - 505km, 58.5 or Polar	15 M km - 112 M km
Duration	30 days - 5 yrs	60 days EDSN nominal, up to 120 days	1 -3yrs
Comms	UHF\ISM	S-band, UHF Beacon, Crosslink UHF	X-Band, DSN
Data Volume	200 kB/month	Storage 16 Gbytes; 180 kBytes/month	~500 kB/month
Data Rate	Downlink 9.6 - 115.1 kbps orbit dependent; Beacon 1200 baud AX.25	Crosslink 3.4 kbps average Downlink >1 kbps historical average Beacon 9600 bps	256 kbps @ LEO 33 kbps @ 0.1 AU 0.5 kbps @ 0.75 AU
Attitude Control / Pointing	+/- 10 deg	+/- 5 deg	+/- 0.25 deg
Position and Pointing	Hysteresis Magnets	Custom ADCS MagTorquers 3 axis reaction wheels Magnetometer Rate Gyro	3-Axis Stabilized 500 m in-track pos. knowledge
GPS	No	Yes	No

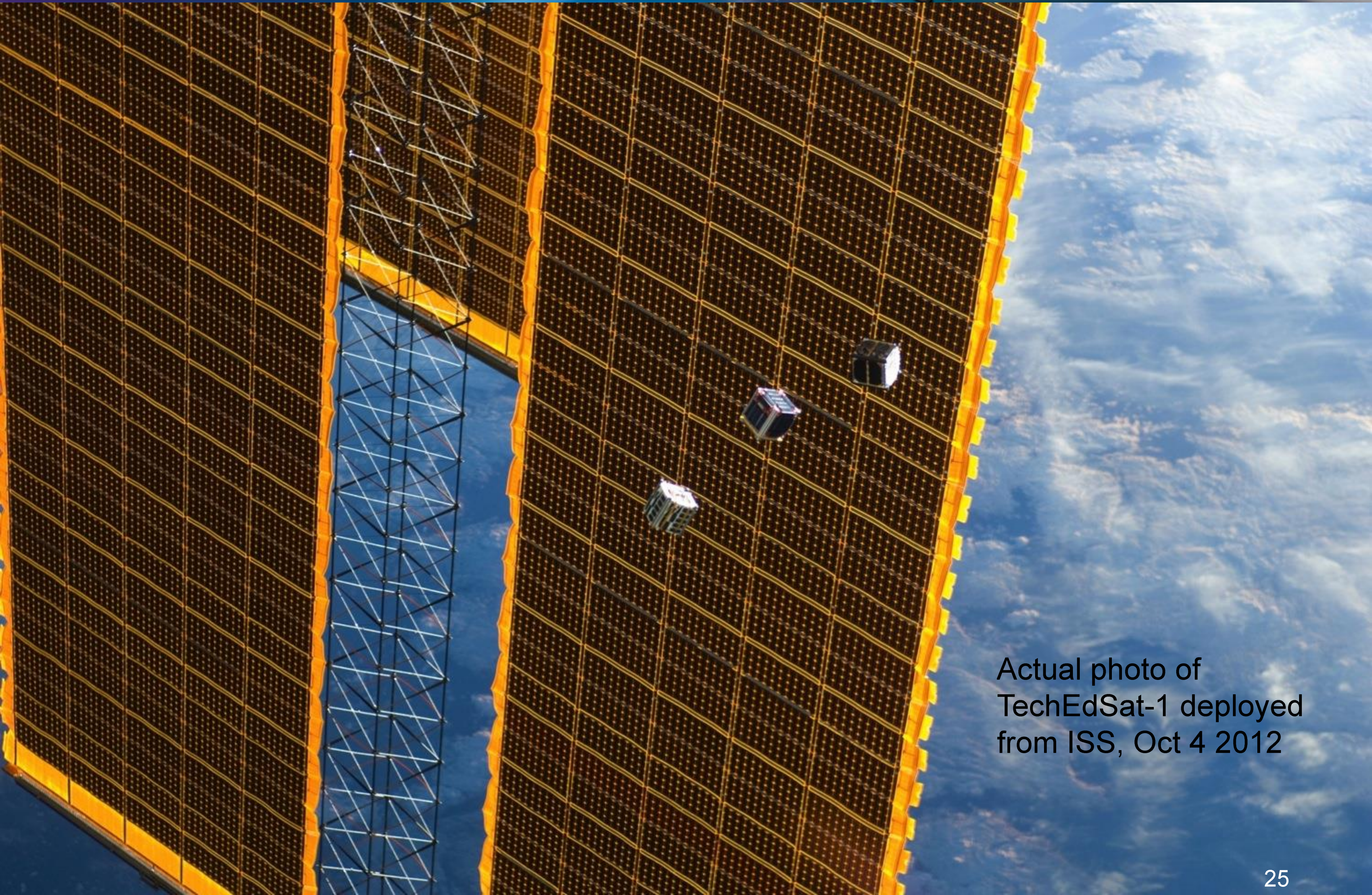
Summary

- NASA Ames leads the Agency in Small spacecraft, Nano-satellite and Cubesat missions.

- NASA Ames is actively developing and operating Smallsats and Nano-satellites for Technology, Science and Exploration missions.
  - Support flight demonstrations of new technologies, capabilities and applications for nanospacecraft.

- NASA Ames actively partners with Universities, International Space Agencies, and other Gov't agencies on Small/Nanosat missions

Questions?



Actual photo of TechEdSat-1 deployed from ISS, Oct 4 2012

Partnerships (1/2)

NASA HQ ultimately leads and negotiates all collaborations with foreign parties. The centers may initiate technical discussions with possible international partners to develop specific concepts for collaboration.

Technical discussions should be at a high level and include only publicly available information.

There needs to be a mutual benefit and a quid pro quo for NASA identified to have a collaboration with a foreign partner.

We do not exchange funds for the collaboration; each side pays for its own work in the joint activity.

Typically, the value of each side's contribution to the activity should be about equal.

Keep in mind that ITAR and Export Control rules apply to technical discussions. Public data is OK to discuss.

In the course of the discussions, if you have a question about disclosing any technical data, please consult with the Center Export Administrator Mary Williams.

Partnerships (2/2)

There is often a need to manage the expectations of foreign partners, who may not be familiar with how we do business. So it's good to explain to them that you are engaging in technical discussions to see if there is a mutual benefit in a collaboration that NASA is interested in, and that there will need to be a formal International Space Act Agreement approved and signed by NASA HQ for the actual collaboration to proceed.

The Agreement must be vetted and approved at the Center level and at HQ. This can take a long time (six - nine months, sometimes longer from the date the vetting process begins).

NASA HQ's Office of International and Interagency Relations will negotiate the Agreement with the foreign partner.

Code B will help you with the process of vetting and gaining approvals for the International Space Agreement.

Keep us posted on the progress of the technical discussions (we are happy to participate) and let us know if you are ready to proceed with a pursuit for an Agreement.

Frequency Allocation: PhoneSat / EDSN / Nodes

PhoneSat 1a, 1b & 2b

- 437.425 MHz – Beacon (Tx) [UHF Amateur]
- Ground Station: World Wide (Amateur)
- Collaboration with students and USRA*
- ~7 day orbital lifetime
- Working with IARU / FCC ~1 year prior to launch

PhoneSat 2.4 & 2.5

- 437.425 MHz – Beacon (Tx) [UHF Amateur]
- 2401.2 – 2431.2 MHz – Space-Ground (Tx/Rx) [S-Band]
- Ground Stations: World Wide (Amatuer) + SCU*
- Collaboration with USRA* and SCU*
- ~6mths, ~12mths orbital lifetime (respectively)
- Working with IARU / FCC ~8 mths prior to launch

*SCU = Santa Clara University

*USRA = Universities Space Research Association

EDSN

- 437.100 MHz – Beacon (Tx) [UHF Amateur]
- 2401.2 – 2431.2 MHz – Space-to-Ground (Tx/Rx) [S-Band]
- 450.075 MHz – Space-to-Space (Tx/Rx) [UHF Broadcast Auxillary]
- Ground Station: SCU* + World Wide (Amateur)
- Collaboration with SCU*
- Working with IARU / FCC ~1 year prior to launch

Nodes

- 437.100 MHz – Beacon (Tx) [Amateur]
- 2401.2 – 2431.2 MHz – Space-Ground (Tx/Rx) [S-Band]
- 450.075 MHz – Space-to-Space (Tx/Rx) [UHF Broadcast Auxillary]
- Ground Station: SCU* + World Wide (Amateur)
- Collaboration with SCU*
- Working with IARU / FCC ~6 mths prior to launch

Frequency Allocation (continued)

Some additional notes:

- Dead-man timer requirement for stopping radio transmission imposes significant risk on S/C success; especially in cases where S/C is deployed with ~30 other S/C and determination of position is difficult resulting in in-ability to contact S/C
- Future want to be looking at optical Space-Ground & Space-Space on cubesats – will this be addressed for streamline process too?
- Use of ISM band in space networks to leverage COTS technology (just a discussion point – WiFi / Bluetooth / Zigbee)
- SpaceCap is not a user friendly piece of software – any possibility in updating this?