National Aeronautics and Space Administration

NASA TECHNOLOGY TRANSFER PROGRAM

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# Welcome to the NASA Ames Technology Transfer Small Satellite Lightning Talk

https://technology.nasa.gov/
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# Transformable Hypersonic Aerodynamic Decelerator (ADEPT)
# NASA Ames Technology Transfer Small Sat Webinar

| | | |
|---|---|---|
| **Ethiraj Venkatapathy** | **and** | **Paul Wercinski** |
| **Senior Technologist** | | **Project Manager** |

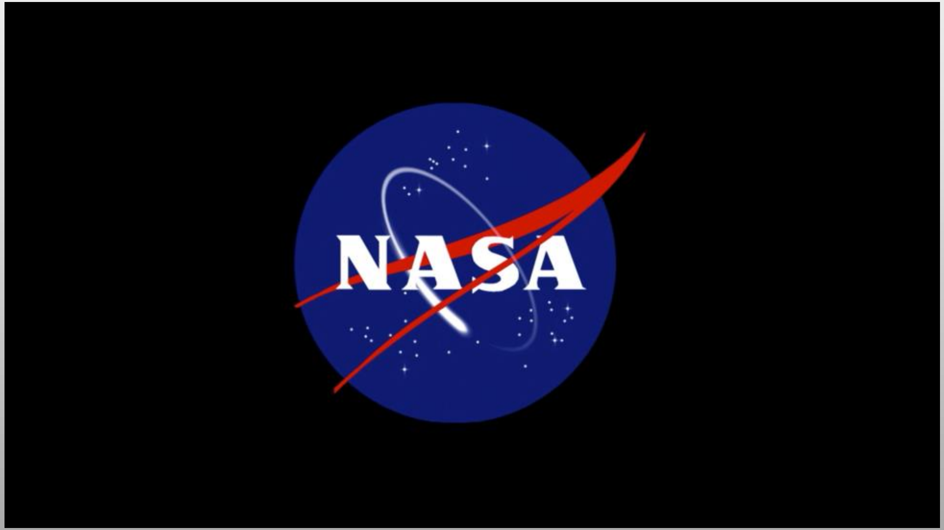
**NASA Ames Research Center**

**10/13/2020**

www.nasa.gov

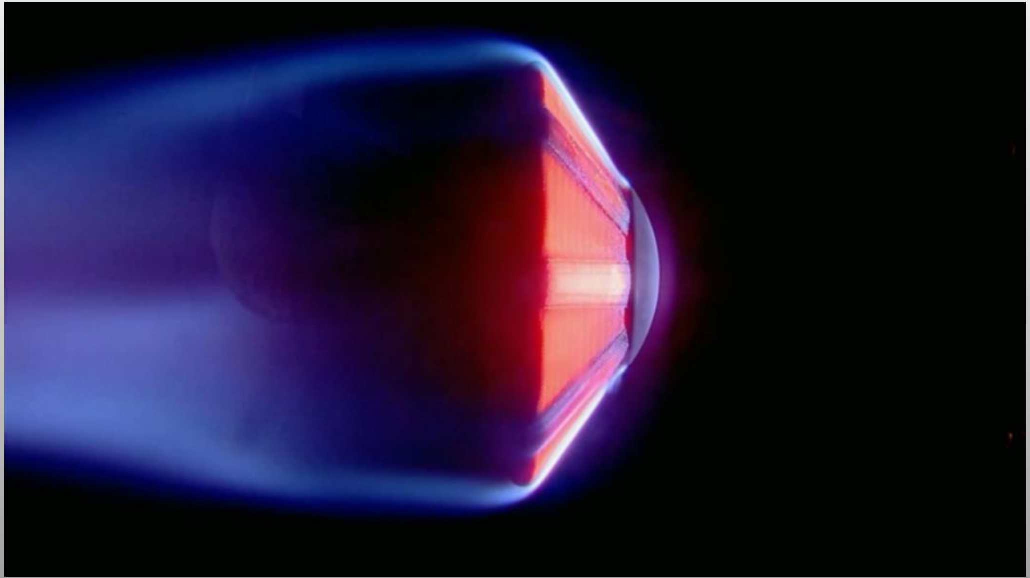
# Technology Overview

- What is **Transformable Hypersonic Aerodynamic Decelerator?**



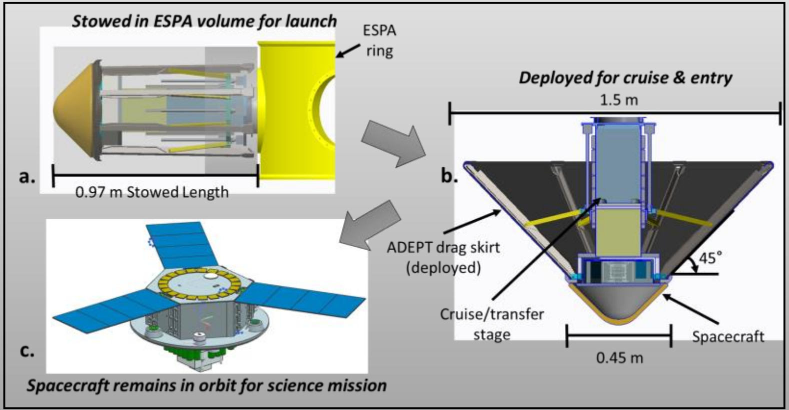
# Technology Overview

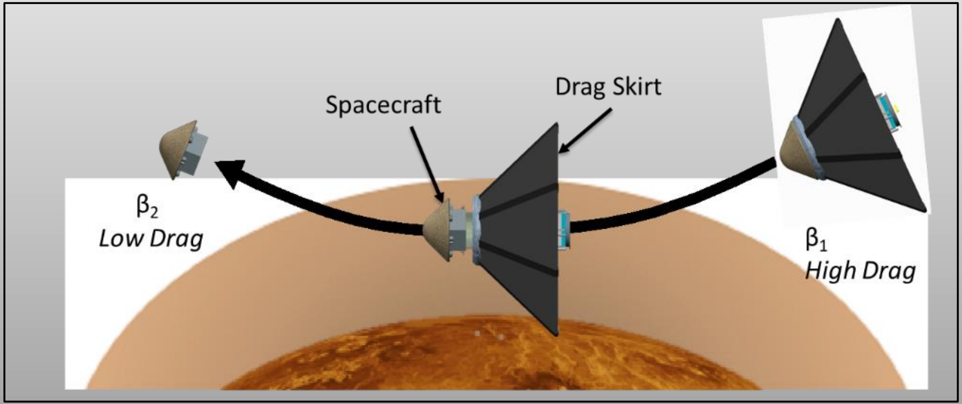
- Technology Maturity



# Technology Overview: SmallSat Application

- **Propulsive insertion is extremely limiting and/or impossible due to the volume needed to accommodate fuel.**
- **Drag Modulated Aerocapture enabled by ADEPT is an enabler of SmallSat Missions to Venus, Mars and other destinations.**

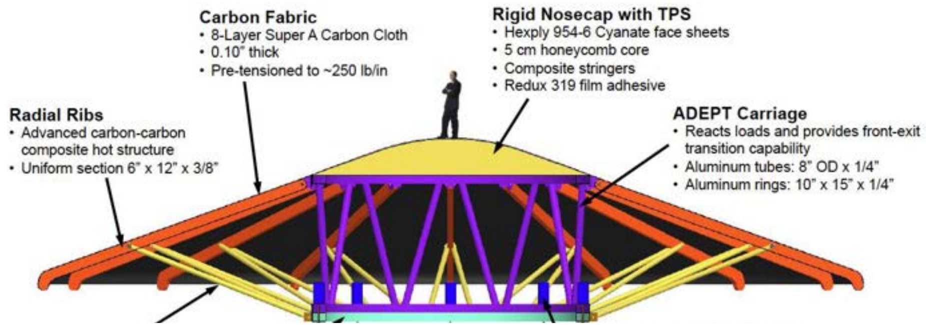




**By modulating the time that a drag skirt is jettisoned from the spacecraft, the system can achieve the delta-V and target a specific orbit for the placement of the spacecraft**

# Applications

## 23m: Mars Exploration



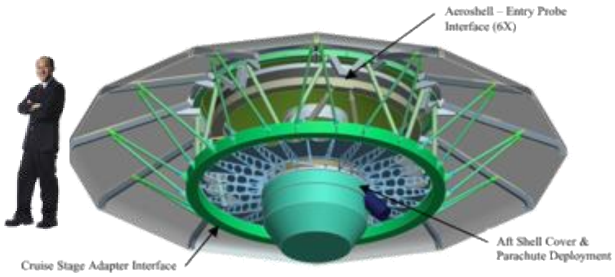
**Carbon Fabric**
- 8-Layer Super A Carbon Cloth
- 0.10" thick
- Pre-tensioned to ~250 lb/in

**Rigid Nosecap with TPS**
- Hexply 954-6 Cyanate face sheets
- 5 cm honeycomb core
- Composite stringers
- Redux 319 film adhesive

**Radial Ribs**
- Advanced carbon-carbon composite hot structure
- Uniform section 6" x 12" x 3/8"

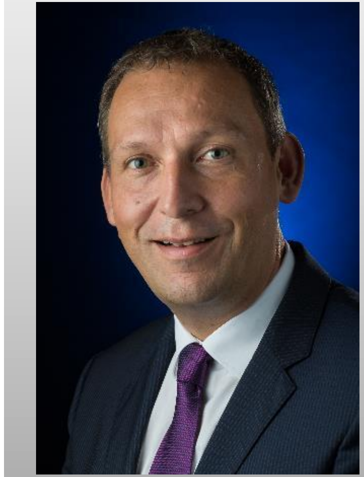
**ADEPT Carriage**
- Reacts loads and provides front-exit transition capability
- Aluminum tubes: 8" OD x 1/4"
- Aluminum rings: 10" x 15" x 1/4"

## 6m: Venus Lander



## 1m: "Nano" ADEPT

**Small, targeted science missions are important to the future of planetary science**



> "We're not going to ask whether we need it. You have to convince us that we don't need it."
>
> — *Thomas Zurbuchen, NASA associate administrator for science, pledging the U.S. space agency to purchase a secondary payload adapter whenever it buys a launch vehicle for a science mission.*

# Applications and Benefits of ADEPT Technology

- **This is a push technology. It is invented to enable missions that are extremely challenging for conventional rigid aeroshells.**
- **Enables Small Sat Missions to Mars and Venus in the near term.**
- **Low deceleration entry for accommodation of sensitive science instruments**
- **Precision sample return mission from Moon**

**Acknowledgement:**

**JPL is leading the Drag Modulated Aerocapture in partnership with Ames.**

- Light weight
- Easily deployable
- Aerodynamic surface can be actuated
- Design can be scaled to fit any size craft or payload
- Support packaging within the launch shroud
- Facilitate redirection
- Accommodate a retro-propulsion system
- Offers a compact entry system solution during the EDL mission segment
- A single ADEPT can perform both aerocapture and atmospheric EDL

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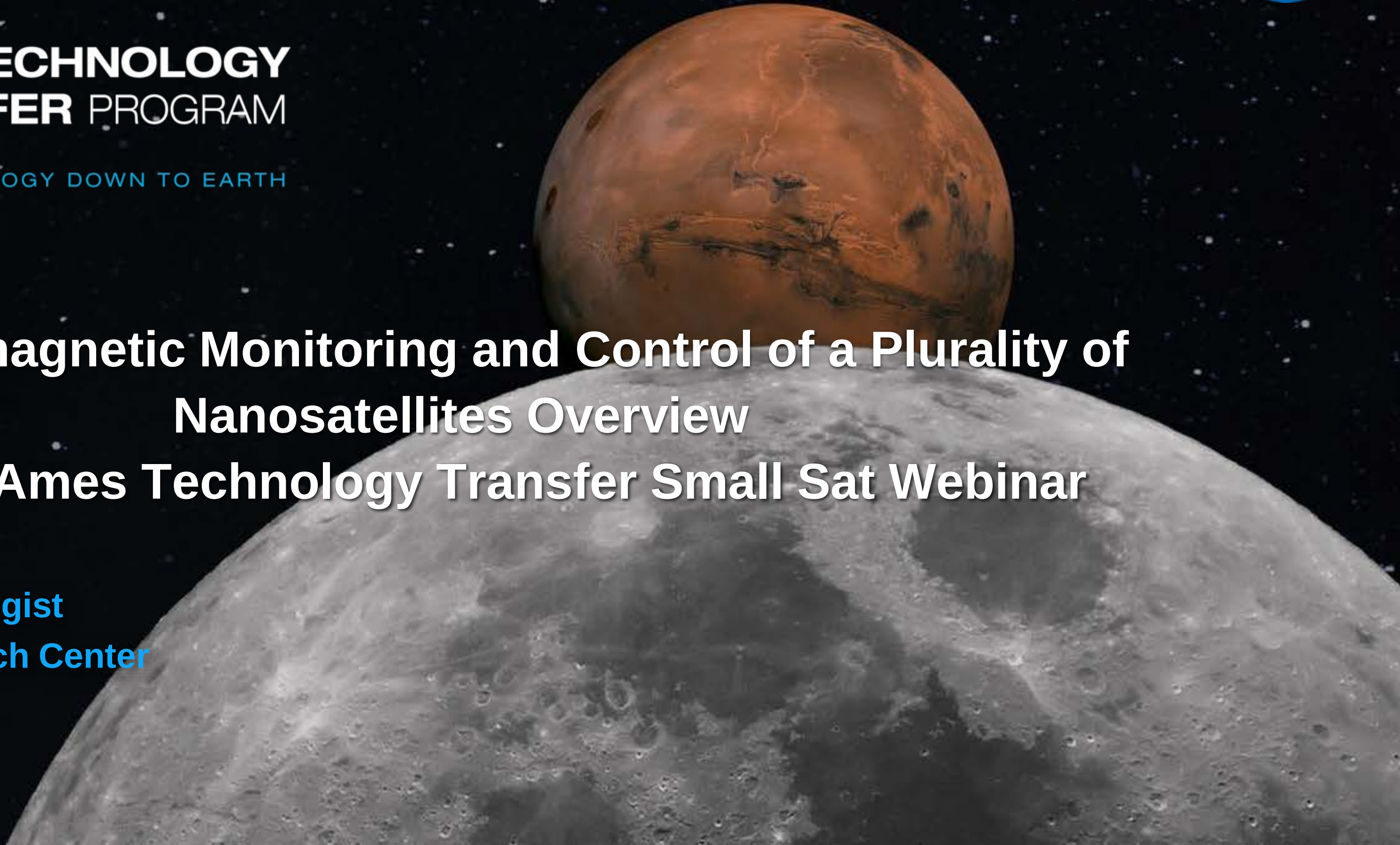


# Electromagnetic Monitoring and Control of a Plurality of Nanosatellites Overview

## NASA Ames Technology Transfer Small Sat Webinar

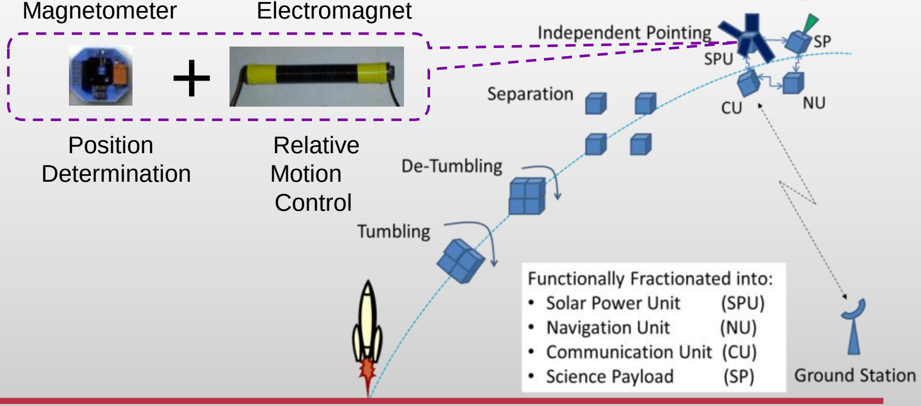
**Don Soloway**
**Aerospace Technologist**
**NASA Ames Research Center**
**10/13/2020**

# Electromagnetic Monitoring and Control of a Plurality of Nanosatellites

## Technology Overview

- **Relative motion control of a cluster of nanosats**
  - **Electromagnets for control actuator**
  - **Magnetometer for relative position determination**
- **Development:**
  - The non-linear coupled force/torque **equations for *n* nanosats have been derived and solved** for control applications
  - A **non-linear control law** has been developed for ***n* nanosats**
  - A 3-DOF simulator for validation has been demonstrated
  - 3-DOF Hardware had been designed and built.

A Functionally Fractionated Nanosat Cluster Controlled By Low Powered Electromagnets



Functionally Fractionated into:
- Solar Power Unit (SPU)
- Navigation Unit (NU)
- Communication Unit (CU)
- Science Payload (SP)

## Applications/Benefits

- **Applications that require nanosats stay in proximity:**
  - Nanosat clusters for multi-point sensing
  - Nanosat clusters for construction of large solar panels
- **Benefits of functional fractionation of a nanosat cluster:**
  - Increased reliability
  - Reduce non-recurring development costs
  - Reduce time from mission concept to flight
  - Reduce mission operations

## Benefits Compared to SOA

- This is a non-propellant based relative motion control, it **uses electricity** which is a **renewable power source**.
- Other EM approaches to control satellites are single dipole based, thus require a reaction wheel for on-axis control. This **uses a multi-dipole configuration** for control, therefore no reaction wheel, thus **no moving parts**.
- **No costly position determination** system, uses **magnetometer for relative position determination**.

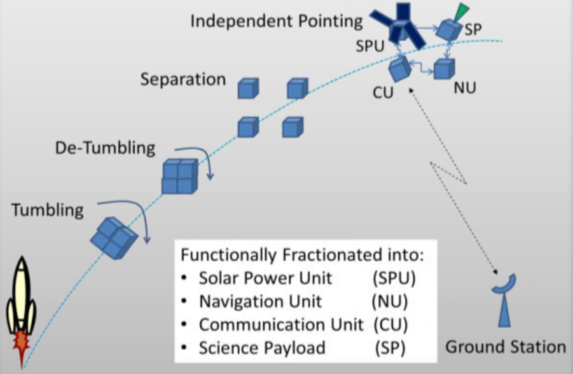
# Applications

- **Fractionation of nanosats**

  **Given a solar power unit (SPU), a communication unit (CU) and a navigation unit (NU)**
  - The mission designer focus on payload design. If more power is needed, add another SPU.
  - The SPU can be positioned as a sun shield
  - The CU can be pointing at Earth
  - The science payload (SP) is free to point where needed.

  **The SPU, CU and NU can be mass produced thus reducing cost and increasing reliability**

Functionally Fractionation Of Nanosats



Functionally Fractionated into:
- Solar Power Unit (SPU)
- Navigation Unit (NU)
- Communication Unit (CU)
- Science Payload (SP)

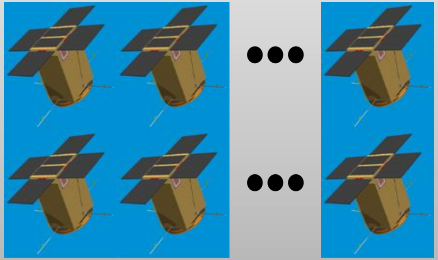
A Functionally Fractionated Nanosat Cluster Controlled by Low Powered Electromagnets

Nanosat Cluster Constellation

One example mission concept enabled is a multi-point Earth observation nanosat cluster constellation.

# Applications

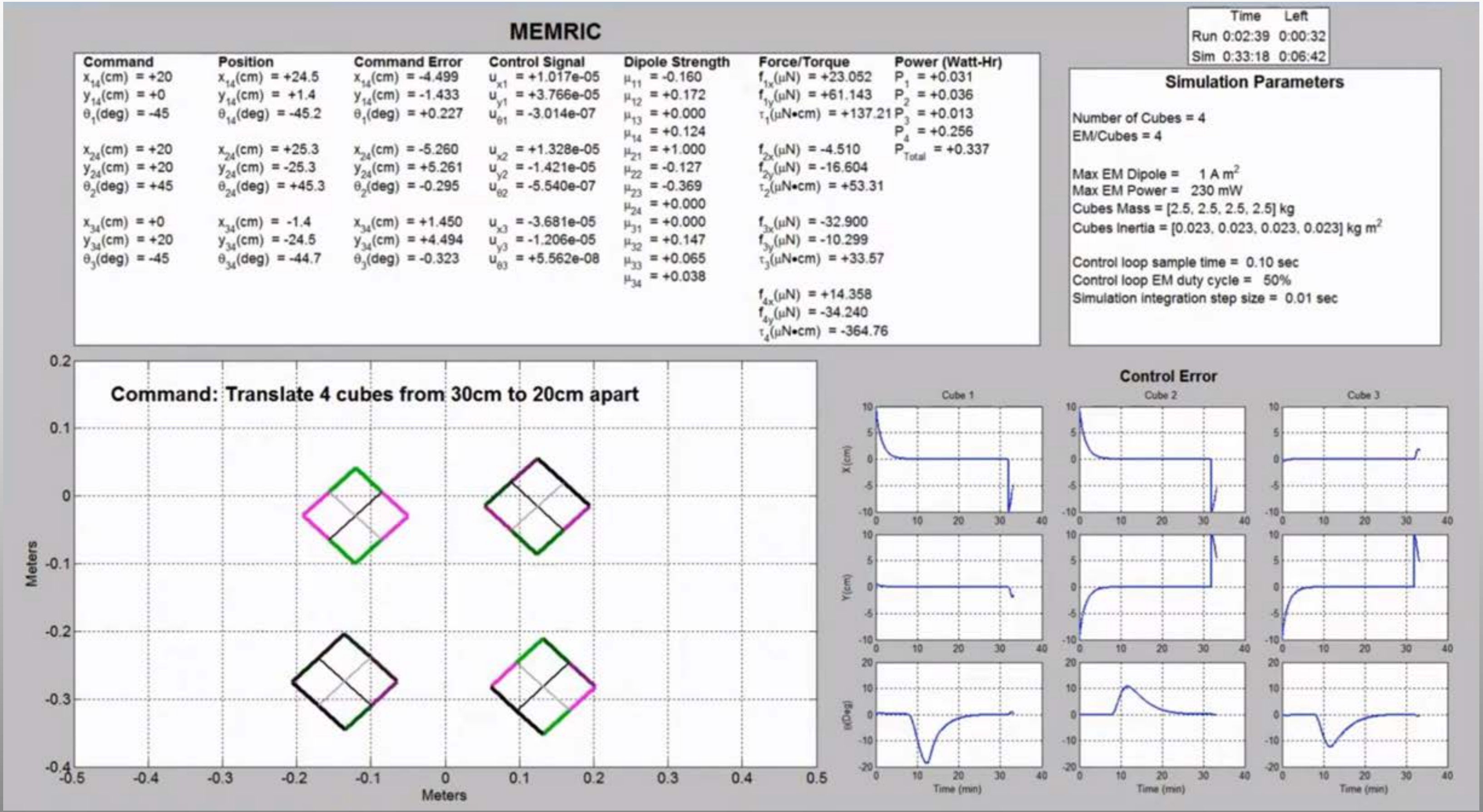
- Space Based Construction



*n* nanosats with solar panels

Solar Panel Array Construction

# 3-DOF Simulator



## MEMRIC

| Command | Position | Command Error | Control Signal | Dipole Strength | Force/Torque | Power (Watt-Hr) |
|---|---|---|---|---|---|---|
| $x_{14}$(cm) = +20 | $x_{14}$(cm) = +24.5 | $x_{14}$(cm) = -4.499 | $u_{x1}$ = +1.017e-05 | $\mu_{11}$ = -0.160 | $f_{1x}$(μN) = +23.052 | $P_1$ = +0.031 |
| $y_{14}$(cm) = +0 | $y_{14}$(cm) = +1.4 | $y_{14}$(cm) = -1.433 | $u_{y1}$ = +3.766e-05 | $\mu_{12}$ = +0.172 | $f_{1y}$(μN) = +61.143 | $P_2$ = +0.036 |
| $\theta_1$(deg) = -45 | $\theta_{14}$(deg) = -45.2 | $\theta_1$(deg) = +0.227 | $u_{\theta 1}$ = -3.014e-07 | $\mu_{13}$ = +0.000 | $\tau_1$(μN•cm) = +137.21 | $P_3$ = +0.013 |
| | | | | $\mu_{14}$ = +0.124 | | $P_4$ = +0.256 |
| $x_{24}$(cm) = +20 | $x_{24}$(cm) = +25.3 | $x_{24}$(cm) = -5.260 | $u_{x2}$ = +1.328e-05 | $\mu_{21}$ = +1.000 | $f_{2x}$(μN) = -4.510 | $P_{Total}$ = +0.337 |
| $y_{24}$(cm) = +20 | $y_{24}$(cm) = -25.3 | $y_{24}$(cm) = +5.261 | $u_{y2}$ = -1.421e-05 | $\mu_{22}$ = -0.127 | $f_{2y}$(μN) = -16.604 | |
| $\theta_2$(deg) = +45 | $\theta_{24}$(deg) = +45.3 | $\theta_2$(deg) = -0.295 | $u_{\theta 2}$ = -5.540e-07 | $\mu_{23}$ = -0.369 | $\tau_2$(μN•cm) = +53.31 | |
| | | | | $\mu_{24}$ = +0.000 | | |
| $x_{34}$(cm) = +0 | $x_{34}$(cm) = -1.4 | $x_{34}$(cm) = +1.450 | $u_{x3}$ = -3.681e-05 | $\mu_{31}$ = +0.000 | $f_{3x}$(μN) = -32.900 | |
| $y_{34}$(cm) = +20 | $y_{34}$(cm) = -24.5 | $y_{34}$(cm) = +4.494 | $u_{y3}$ = -1.206e-05 | $\mu_{32}$ = +0.147 | $f_{3y}$(μN) = -10.299 | |
| $\theta_3$(deg) = -45 | $\theta_{34}$(deg) = -44.7 | $\theta_3$(deg) = -0.323 | $u_{\theta 3}$ = +5.562e-08 | $\mu_{33}$ = +0.065 | $\tau_3$(μN•cm) = +33.57 | |
| | | | | $\mu_{34}$ = +0.038 | | |
| | | | | | $f_{4x}$(μN) = +14.358 | |
| | | | | | $f_{4y}$(μN) = -34.240 | |
| | | | | | $\tau_4$(μN•cm) = -364.76 | |

| | Time | Left |
|---|---|---|
| Run | 0:02:39 | 0:00:32 |
| Sim | 0:33:18 | 0:06:42 |

**Simulation Parameters**

Number of Cubes = 4
EM/Cubes = 4

Max EM Dipole = 1 A $m^2$
Max EM Power = 230 mW
Cubes Mass = [2.5, 2.5, 2.5, 2.5] kg
Cubes Inertia = [0.023, 0.023, 0.023, 0.023] kg $m^2$

Control loop sample time = 0.10 sec
Control loop EM duty cycle = 50%
Simulation integration step size = 0.01 sec

Command: Translate 4 cubes from 30cm to 20cm apart

# Hardware for Demonstration

- Two 3-DOF EM hardware mounted of two air bearing carriages
- Electronics in the center to control the electromagnets
- Carriage and coils 23 kg
- Max dipole moment per EM is 8 A $m^2$
- Demonstrated sufficient force to move carriage

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# Heterogeneous Spacecraft Network Overview
# NASA Ames Technology Transfer Small Sat Webinar

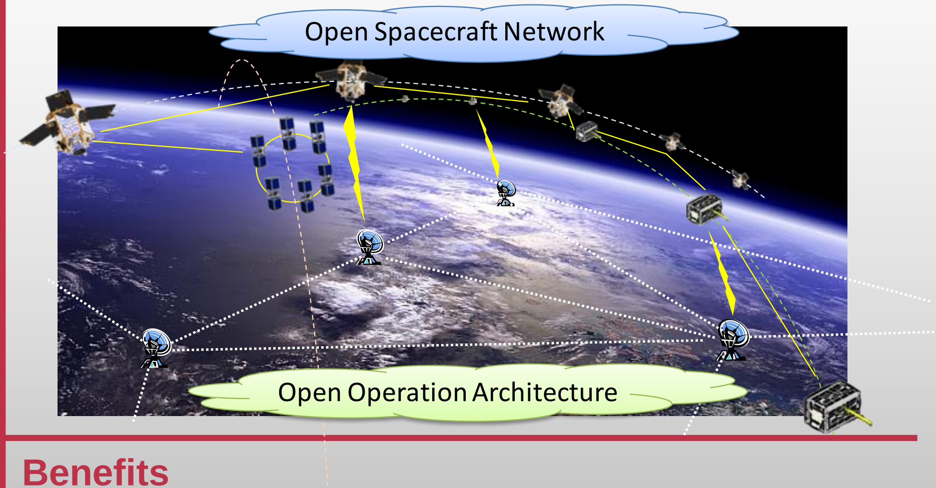
**Richard Alena**
**Computer Engineer**
**NASA Ames Research Center**
**10/13/2020**

www.nasa.gov

# Heterogeneous Spacecraft Networks (HSN)

## Technology Overview

- Concept by NASA/ESA/JAXA Small Satellite team - US Patent # 9,906,291 Feb. 27, 2018
- Commercial standards-based communication technology creates open spacecraft networks for flexible operation of coordinated Small Satellites
- The Internet enables autonomous operation using distributed Virtual Operation Centers for controlling multiple satellites from different Organizations



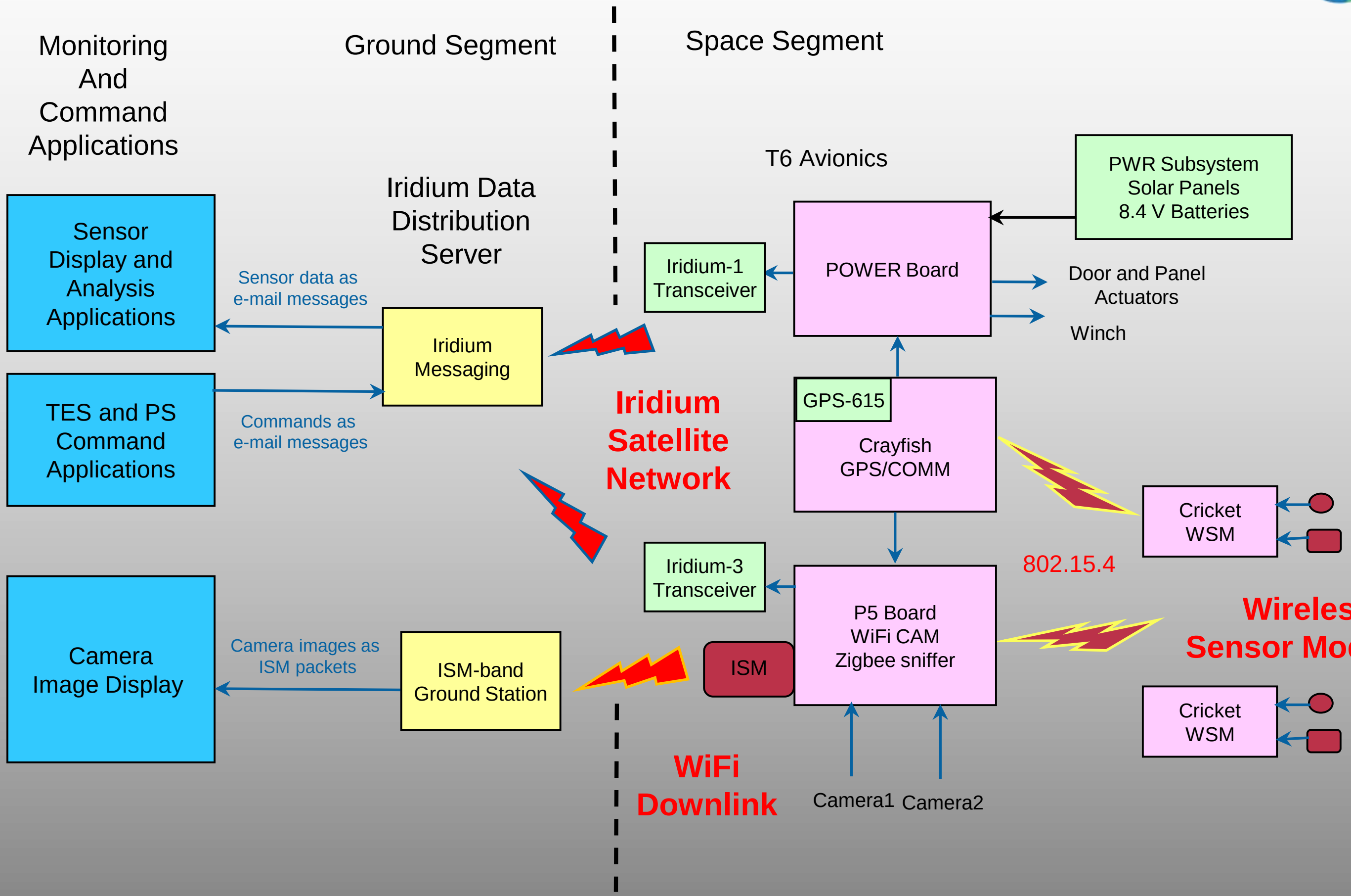
## Applications

- Multiple Organizations can fly coordinated satellites for Earth Observations using coordinated Virtual Operations Centers
- Can integrate multiple communication modalities for improving mission capability and reliability
- NASA TechEdSat demonstrated communications technology such as Iridium Constellation with Zigbee proximity links and WiFi downlink

## Benefits

- Enable simultaneous and complementary data collection and distribution with higher throughput and reliability for multiple spacecraft and partners
- Commercial communication can cost a fraction of conventional space technology
- Supports coordinated heterogeneous swarms
- Scalable, multi-purpose and continuously evolving platform for technology innovation

# TechEdSat-6 Flight System Architecture



Monitoring And Command Applications

Ground Segment

Space Segment

Sensor Display and Analysis Applications

TES and PS Command Applications

Camera Image Display

Sensor data as e-mail messages

Commands as e-mail messages

Camera images as ISM packets

Iridium Data Distribution Server

Iridium Messaging

ISM-band Ground Station

**Iridium Satellite Network**

**WiFi Downlink**

T6 Avionics

Iridium-1 Transceiver

POWER Board

PWR Subsystem
Solar Panels
8.4 V Batteries

Door and Panel Actuators

Winch

GPS-615

Crayfish GPS/COMM

Iridium-3 Transceiver

ISM

P5 Board
WiFi CAM
Zigbee sniffer

Camera1

Camera2

802.15.4

Cricket WSM

Cricket WSM

**Wireless Sensor Modules**

Inter-element, space constellation and direct space-to-ground links are shown in red

# TechEdSat-6 Deployment from ISS
# November 2017

National Aeronautics and Space Administration

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# Low Cost Star Tracker Software Overview
# NASA Ames Technology Transfer Small Sat Webinar

**Stevan Spremo**
**NASA Ames Research Center**
**10/13/2020**

# Low Cost Star Tracker Software

## Technology Overview

- Utilizes low power, highly accurate, and inexpensive, iterative pattern matching approach to identify a star configuration and associated spatial viewing direction in a database that corresponds to an observed star configuration.
- Code timing optimized for spacecraft applications
- Code can be easily adapted by adjusting camera/optics parameters within the code variables
- Prototyped utilizing a Lumenera LW230 monochrome machine-vision camera and a FUJINON HF35SA-1 35mm lens.

## Applications

- Space launch vehicles
- Remote sensing satellites
- Small spacecraft
- Star Tracker Control Systems

## Benefits

- COTSAT Configuration capable of approximately 10 arcsecond precision and has approximate 8 degree field of view
- Low Cost/Design to utilize commercial cameras
- Software can be adapted to multiple operating systems
- Highly accurate attitude GNC capability using COTS hardware
- Modular software design architecture
- Customized user defined settings coded in software

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# Cost Optimized Test of Spacecraft Avionics and Technologies(COTSAT) Modular Spacecraft Software Architecture Overview

## NASA Ames Technology Transfer Small Sat Webinar

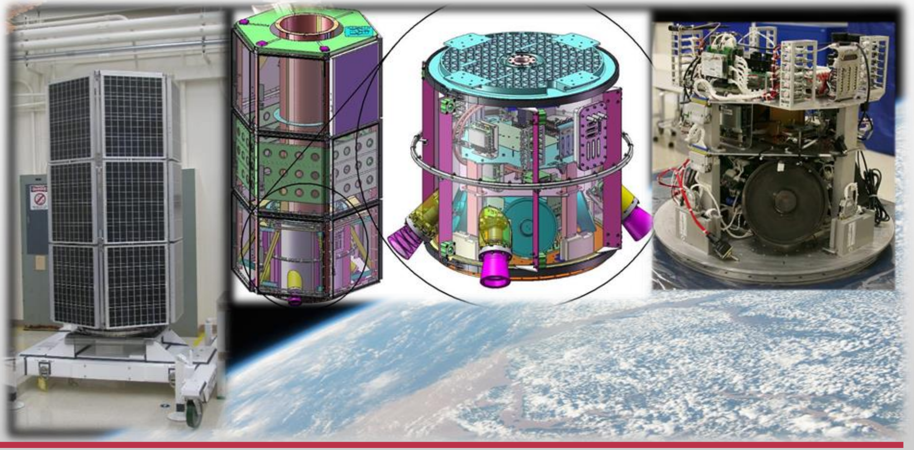
**Stevan Spremo**
**NASA Ames Research Center**

**10/13/2020**

# Cost Optimized Test of Spacecraft Avionics and Technologies (COTSAT)

## Technology Overview

- Developed over a three year timeframe at NASA Ames Research Center. The project achieved a successful prototype of a remote sensing small spacecraft reducing cost by 1 to 2 orders of magnitude per subsystem. (A fully integrated prototype was built and demonstrated and tested in lab setting) TRL 5-6. Patent
- Particular focus was placed on a modular software architecture and hardware architecture
- The COTSAT avionics platform is a modular design intended to prove a low-cost access to space for small spacecraft remote-sensing payloads. Overall many aspects of system architecture and designs remains scalable and reconfigurable across a range of small spacecraft mass categories (Cubesat to a full range of small Spacecraft mass categories).
- COTSAT's enabling low cost approach consists of: An artificial environment container, modular platform, electrical power system, command and data handling system, modular software architecture, three axis-attitude and determination and control systems



## Applications

- Low Cost Spacecraft Architecture (Software and Hardware)
- Low Earth Orbit Satellite Swarm/Constellations
- Short Mission Duration Remote sensing satellite applications
- Commercial Off The Shelf/Government of the Shelf Applications Subsystem Demonstration Missions
- Small Satellite Form Factor (applications range from Cubesat Class 5kg to Small Spacecraft 500kg class)
- Modular Software Spacecraft Operating System

## Benefits

- Rapid prototype platform, can replicate copies quickly with low cost COTS subsystems to achieve a fleet of fully integrated low cost spacecraft. Satellite single production cost expected to range from $1 million to $5million per copy range including parts and labor.
- Pressurized Hardware and Modular Software Architecture enables technology reducing cost
- Single atmosphere artificial avionics environment replicates Earth-like atmosphere improving reliability and significantly mitigating space environments risk while reducing testing costs and reducing cost to achieve design margins required for a successful flight within the avionics platform.
- Robust Interface Architecture allows interchangeable, subsystems, payloads and new technologies. Upgrading with new avionics subsystems designed to have minimal to no impact to overall design if needed.
- Radiation tolerant, safe mode software architecture
- Modular Software Subsystem Design features that allow applicability to a range of CubeSat and SmallSat Hardware interfaces

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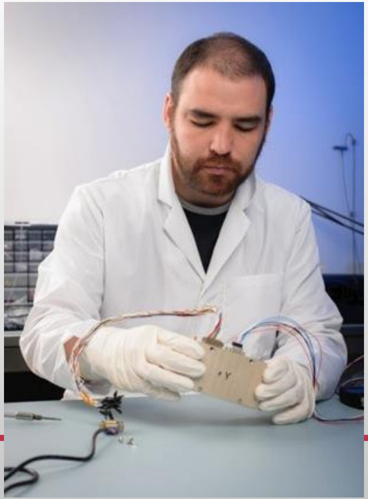
# Affordable Vehicle Avionics (AVA) Overview
# NASA Ames Technology Transfer Small Sat Webinar

**Arwen Davé**
**Project Manager**
**NASA Ames Research Center**
**10/13/2020**

# Affordable Vehicle Avionics (AVA)

## Technology Overview

- AVA consists of hardware, software, and **a method**
- Uses COTS sensors paired with a Kalman filter to reduce 'noise' of lower-cost hardware
- Scaled down to fit Nano-launch vehicles
- Cost reduced **by order of magnitude** over conventional high-performance, high-reliability LEO avionics



## Applications

AVA can be **tailored** for:

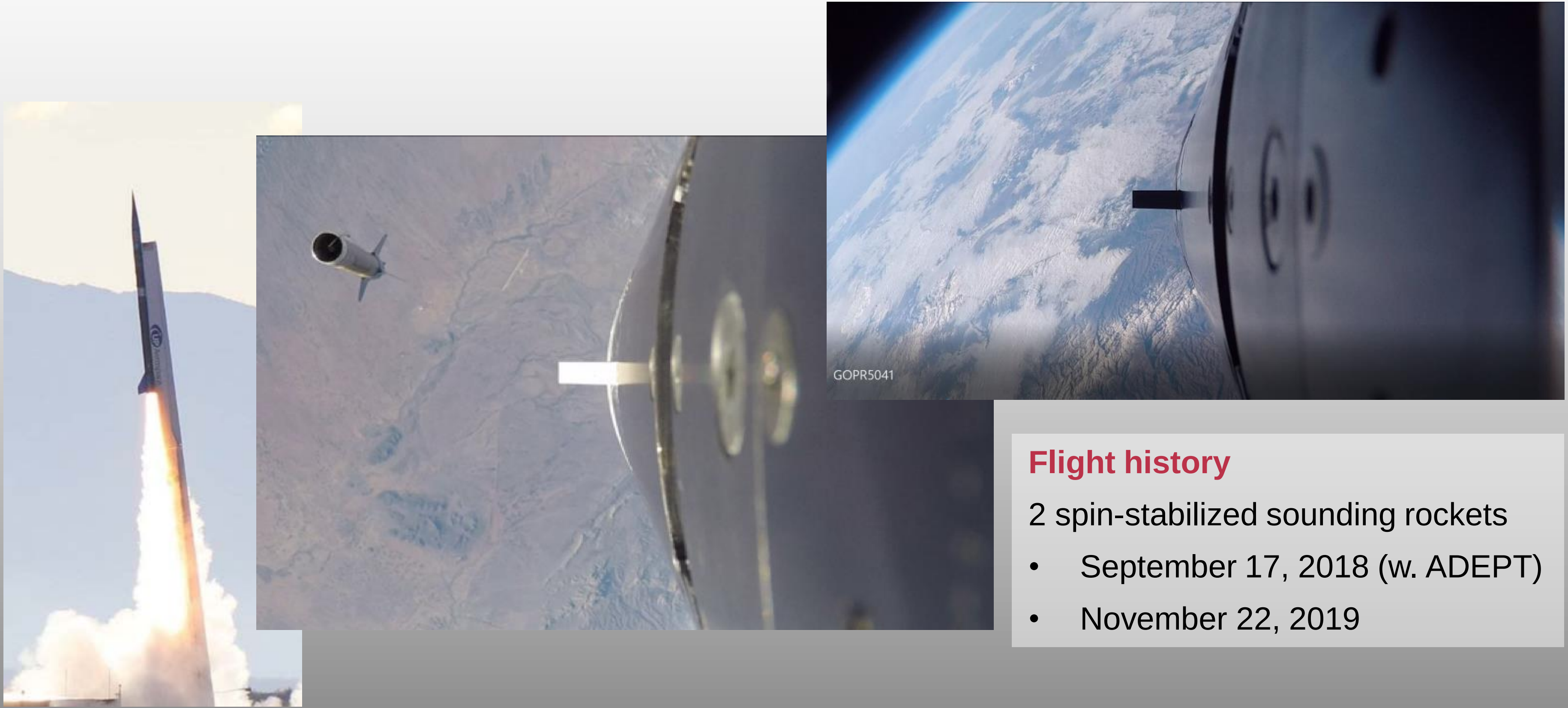
- Launch vehicles for sounding and LEO orbits
- Single- and multi- stage launch vehicles
- Spin-stabilized launch vehicle stages

**By the licensee**

## Benefits with AVA:

- Nano-launch providers can reduce avionics costs by an order of magnitude over conventional systems
- **Nano-sats** can afford to ride to LEO as **primary payloads**
- Nano-sats can specify their own launch and orbit parameters

# Affordable Vehicle Avionics (AVA)



## Flight history

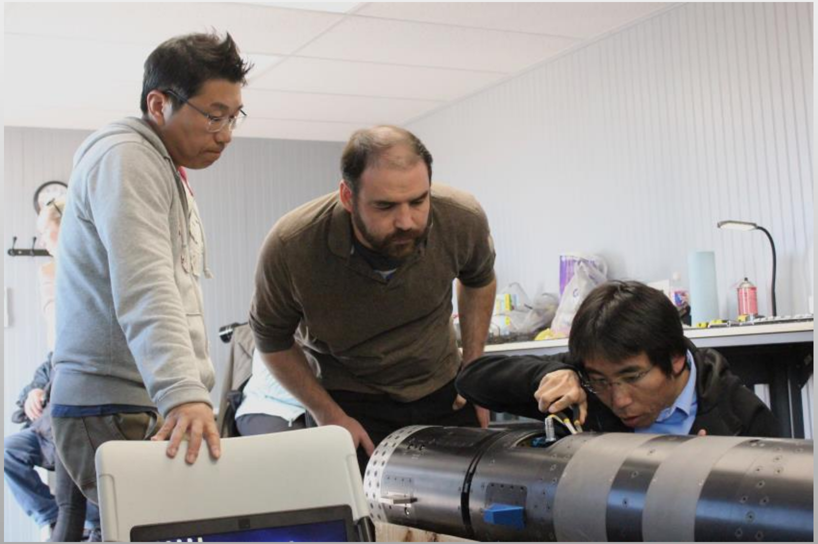
2 spin-stabilized sounding rockets

- September 17, 2018 (w. ADEPT)
- November 22, 2019

# Affordable Vehicle Avionics (AVA)

## Demonstrated

| Capability | Flight | TRL |
|---|---|---|
| Roll-axis closed loop control | SL-11 | 7 |
| 3-axis attitude control | Air Bearing | 4 |
| 2nd stage firing control | SL-14 | 7 |
| GPS signal maintenance | SL-14 | 7 |



## Up next: Licensees to demonstrate their own versions

NASA Technology
Transfer Program

# Space Optical Communications using Laser Arrays for CubeSats in Low Earth Orbit (LEO) or Low Lunar Orbit (LLO)

NASA Ames Technology Transfer Small Sat Webinar

Peter M. Goorjian

NASA Ames Research Center

October 13, 2020

# INTRODUCTION

- A new method for space optical communication using laser arrays for CubeSats in LEO or LLO

- Combines a lens system and a vertical cavity surface-emitting laser (VCSEL)/Photodetector Array, both mature technologies, in a novel way

- Possible applications include:
  - Fine pointing of laser beams: augments body pointing by CubeSats
  - Optical Multiple Access (OMA); simultaneously communicate with ground stations at different locations
  - Wavelength-Division Multiplexing (WDM): increase data rate transmission

- The NASA ARTEMIS Program will include LunaNet, a lunar communications and navigation network
  - A constellation of CubeSats in LLO, 100 km, could form part of LunaNet

- In computer simulations, this method has been applied for laser beam propagation from satellites in LEO and LLO; including NASA's Optical Communications and Sensors Demonstration (OCSD)

# Comparison to Other Methods

- Fine pointing of laser beams:
  - One method uses a quad-cell photodetector to refine the body pointing of the CubeSat; TBIRD
  - Another method uses a fast steering mirror for fine pointing; LaserCube System
  - Both methods change the direction of the laser beam by moving physical parts or the CubeSat
  - The present method uses a laser array with different lasers for fine pointing; no physical moving, rather electronic switching on the nanosecond time scale, much faster
- Optical Multiple Access (OMA):
  - One method uses separate telescopes and lasers for each direction; inter-satellite omnidirectional optical communicator (ISOC)
  - The present method is more compact, uses a VCSEL array and one simple small telescope
- Wavelength-Division Multiplexing (WDM):
  - One method uses a different lens design and uses only VCSEL arrays for open-loop transmissions. A separate device is needed to provide closed-loop transmissions; OptiPulse
  - The present method uses a lens system that has been used in computed simulations for laser propagation at LEO and LEO distances. It can use VCSEL arrays for open-loop transmissions or VCSEL/Photodetector Arrays for closed-loop transmissions

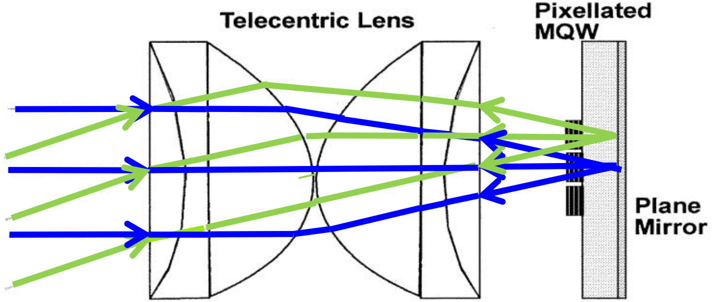
# Additional Features, Market Assessments, Refs

- No optical amplifier; optical power obtained from VCSELs in a cluster
- No optical modem; beam modulation obtained from small-signal current modulation
- This system is simple, static, compact and has small size, weight, and power (SWaP)
- Market Studies by ARC Technology Transfer Office
  - NASA Market Assessment, October 14, 2015; NTR: ARC-17122-1B
    - Recommendation Action: Broad Pursue (Highest Recommendation)
    - Potential commercialization partners and/or licensees could emerge most likely from the smallsat/CubeSat sector; many companies listed
  - NASA Ames Case ARC-18400-1, September 27, 2019; Commercialization evaluation
- Patents: Patent No: 9,774,395; 9,954,613, also Patent Pending: Ames Case ARC-18400-1
- Link: https://ntts-prod.s3.amazonaws.com/t2p/prod/t2media/tops/pdf/TOP2-287.pdf

# NEW CONCEPT FOR LASER BEAM POINTING

**Figure 1**

## Technical Approach



Lens System with (VCSEL)/ Photodetector Array

- An incoming laser beam (green or blue, with rightward arrows), transmitted from a ground terminal, enters the lens system, which directs it to an element of the pixel array (gray rectangle). Angle determines position
- Each element, or pixel, consists of a VCSEL component/Photodetector pair
- The photodetector detects the (possibly weak) incoming beam, and the VCSEL component returns a strong modulated beam (green or blue, with leftward arrows) to the lens system, which sends it to the ground terminal
- As the incoming beam changes direction, e.g., from the blue to the green incoming direction, this change is detected by the photodetectors, and a laser adjacent to the detecting photodetector is turned on to keep the outgoing laser beam on target
- The laser beams overlap so that the combined returning beam continues to cover the ground terminal
- The VCSEL component may consist of a single VCSEL or a cluster of VCSELs.

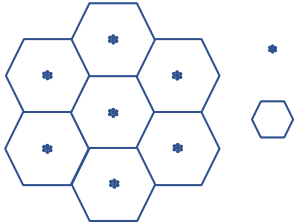
# Initial Laboratory Development of System

- Possible Developers
    - Kent D. Choquette: U Illinois, Elect. and Computer Eng. Dept
        - Fabricate initial VCSEL/Photodetector arrays
    - Govind P. Agrawal: U Rochester, Inst. of Optics
        - Test initial system of VCSEL/Photodetector arrays with lenses
- Possible use of university laboratory facilities

# NEW CONCEPT FOR LASER BEAM POINTING

## VCSEL/ Photodetector Array

- Candidate VCSEL/ Photodetector Array



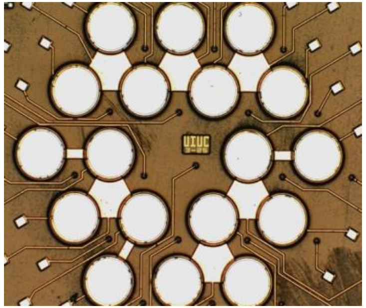
VCSEL Cluster

Photodetector

- Example of a fabricated Array

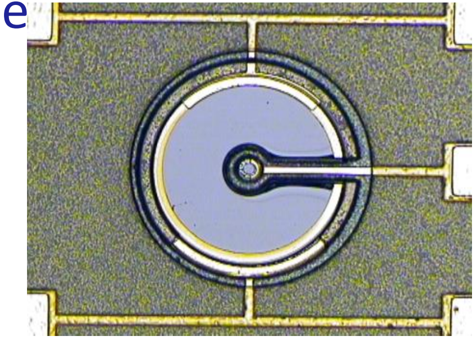
  Photodetectors are PIN
  (p-type/intrinsic/n-type) detectors

Top-view of a 37-element VCSEL / PIN detector array. VCSELs are small black dots and photodetectors are large white circles



- Example of a fabricated VCSEL/PIN couple

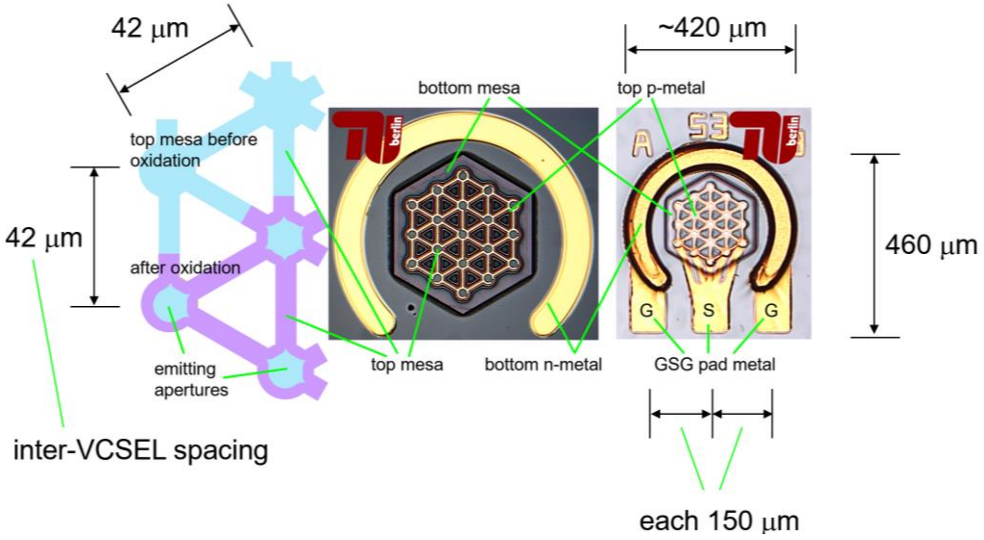
Top-view of a VCSEL/PIN couple. VCSEL at center of photodetector

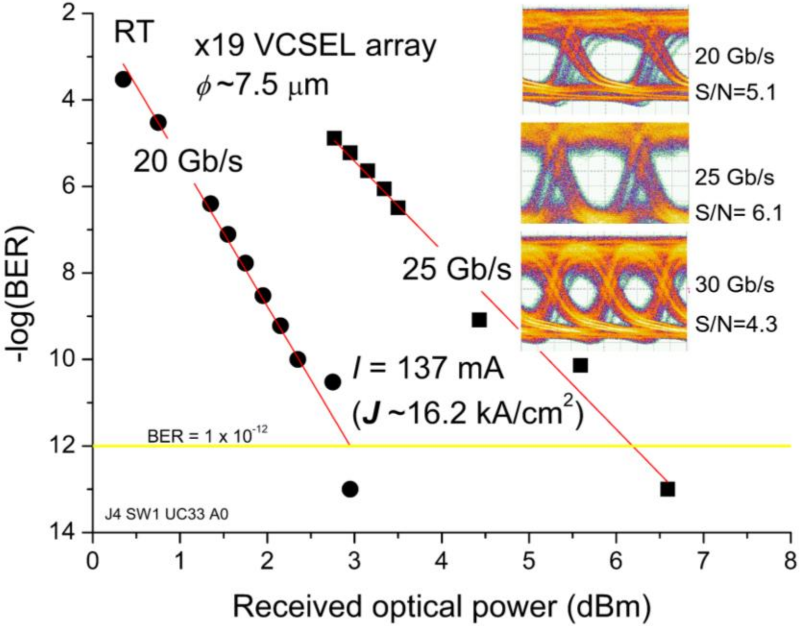


Kent D. Choquette: U Illinois, Elect. and Computer Eng. Dept

# Example of a Fabricated VCSEL Cluster

- 19-element, electrically parallel 980 nm VCSEL array
- bandwidth (18 GHz)
- optical output power (150 mW)
- wall plug efficiency (30%)





Nasibeh Haghighi, Philip Moser, Martin Zorn and James A Lott; 2020 Journal of Physics Photonics in press

NASA TECHNOLOGY TRANSFER PROGRAM

BRINGING NASA TECHNOLOGY DOWN TO EARTH

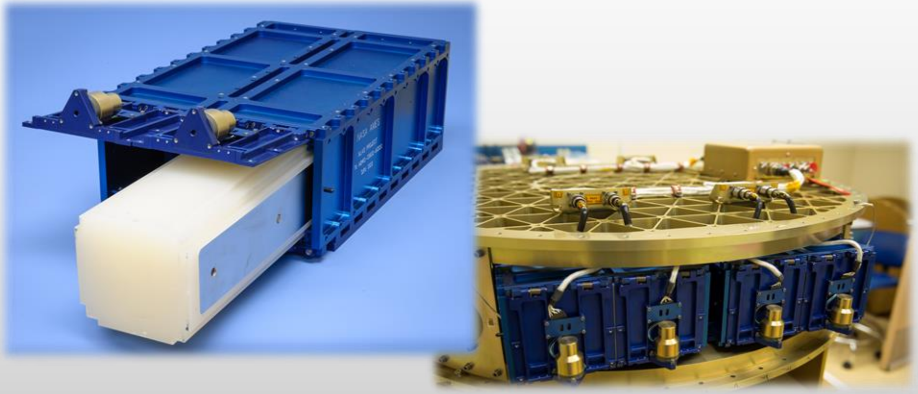
# Nanosatellite Launch Adapter System Overview
# NASA Ames Technology Transfer Small Sat Webinar

**Shakib M. Ghassemieh**
**Flight Systems Engineer**
**NASA Ames Research Center**
**10/13/2020**

# Nanosatellite Launch Adapter System (NLAS)

## Technology Overview

- Consists of an adapter, four dispensers, and a sequencer
- The Adapter takes advantage of the frequently unused volume within the rocket fairing. It fits up to 4 NLAS Dispenser units, or 8 eight Poly-PicoSatellite Orbital Deployers (P-PODs), or any combination thereof
- NLAS deployment Sequencer is an internally powered subsystem which accepts an initiation signal from the launch vehicle and manages the actuations for each deployment device per a user programmable time sequence



## Applications

- Cubesats/Nanosatellites
- Launch vehicles/Secondary payloads
- P-PODs
- Actuator Management
- Sequencing
- Multi-spacecraft missions/ Constellation spacecraft
- Deployers

## Benefits

- Utilizes unused launch vehicle mass and fairing volume
- User configurable deployment ejection timing sequences
- Up to 54kg/24U capacity
- Compatible with standard launch vehicle interfaces
- Internally powered
- P-POD compatible
- Reduced integration time and cost