Space: It's Not What it Used to Be. So What?-

Dellingr, Questions About SmallSats, a Few Answers, and the Need for Transformative Thought in a Transformative Time

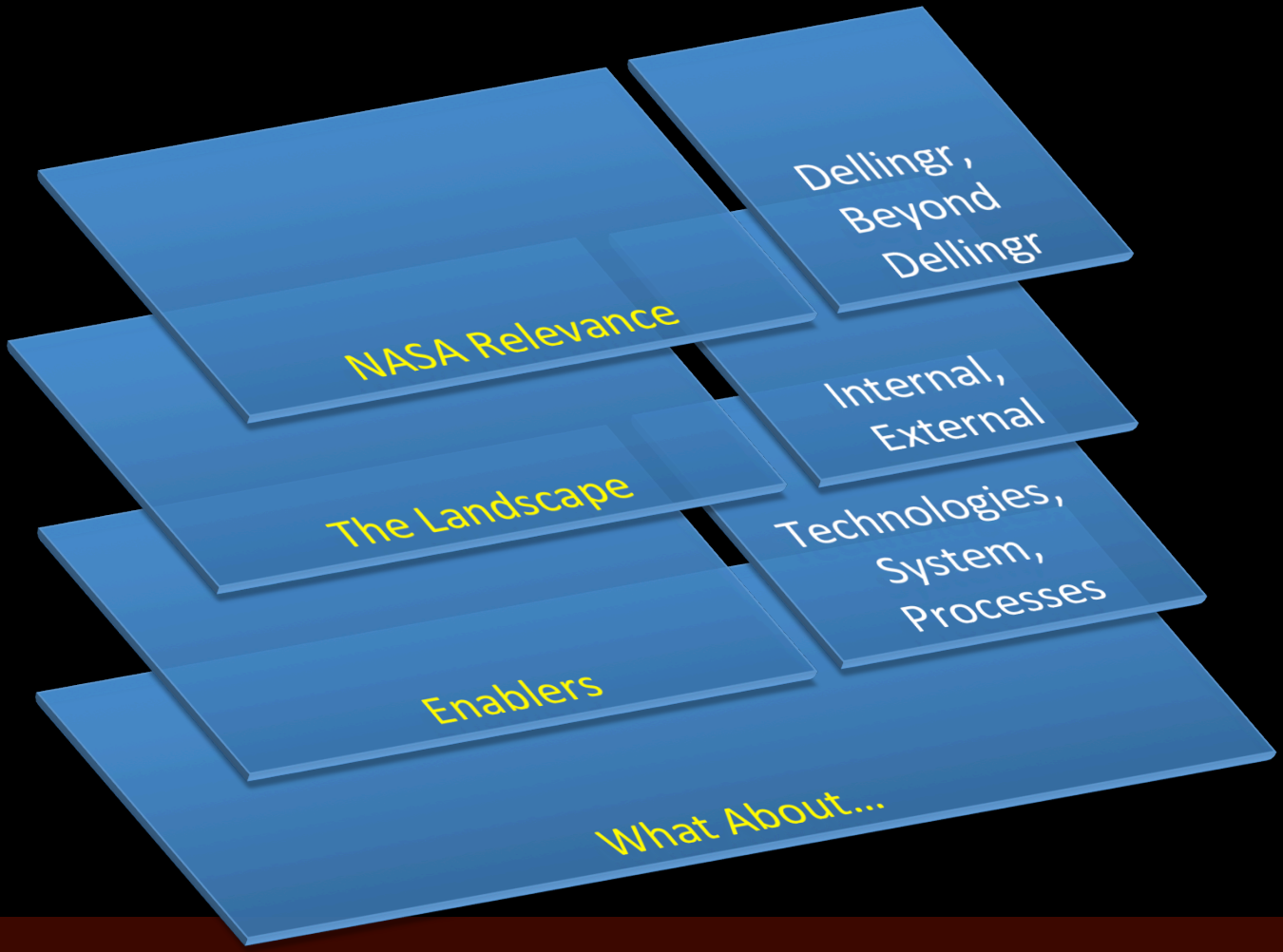
Michael A. Johnson
Chief Technologist
Applied Engineering and Technology Directorate
NASA Goddard Space Flight Center

Imagination is more important than knowledge.

Albert Einstein

Goddard Systems Engineering Colloquium
3 November 2015

Discussion Topics

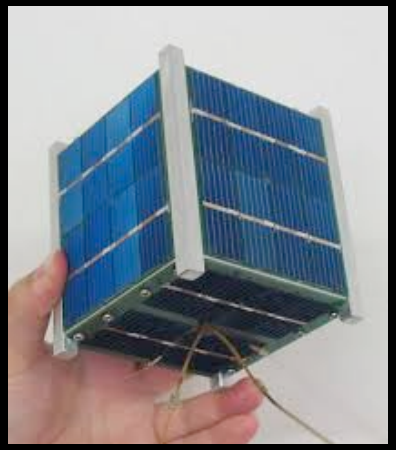


CubeSats and SmallSats are merely part of a larger discussion.

What Is a CubeSat?

A miniaturized satellite (nanosat) consistent with standardized form factors used for space applications

- Developed by California Polytechnic State University and Stanford University in 1999
- Consists of any number of 10 x 10 x 10 cm units or “U”s
- Each “U” has a mass close to 1 kg and not to exceed 1.33 kg



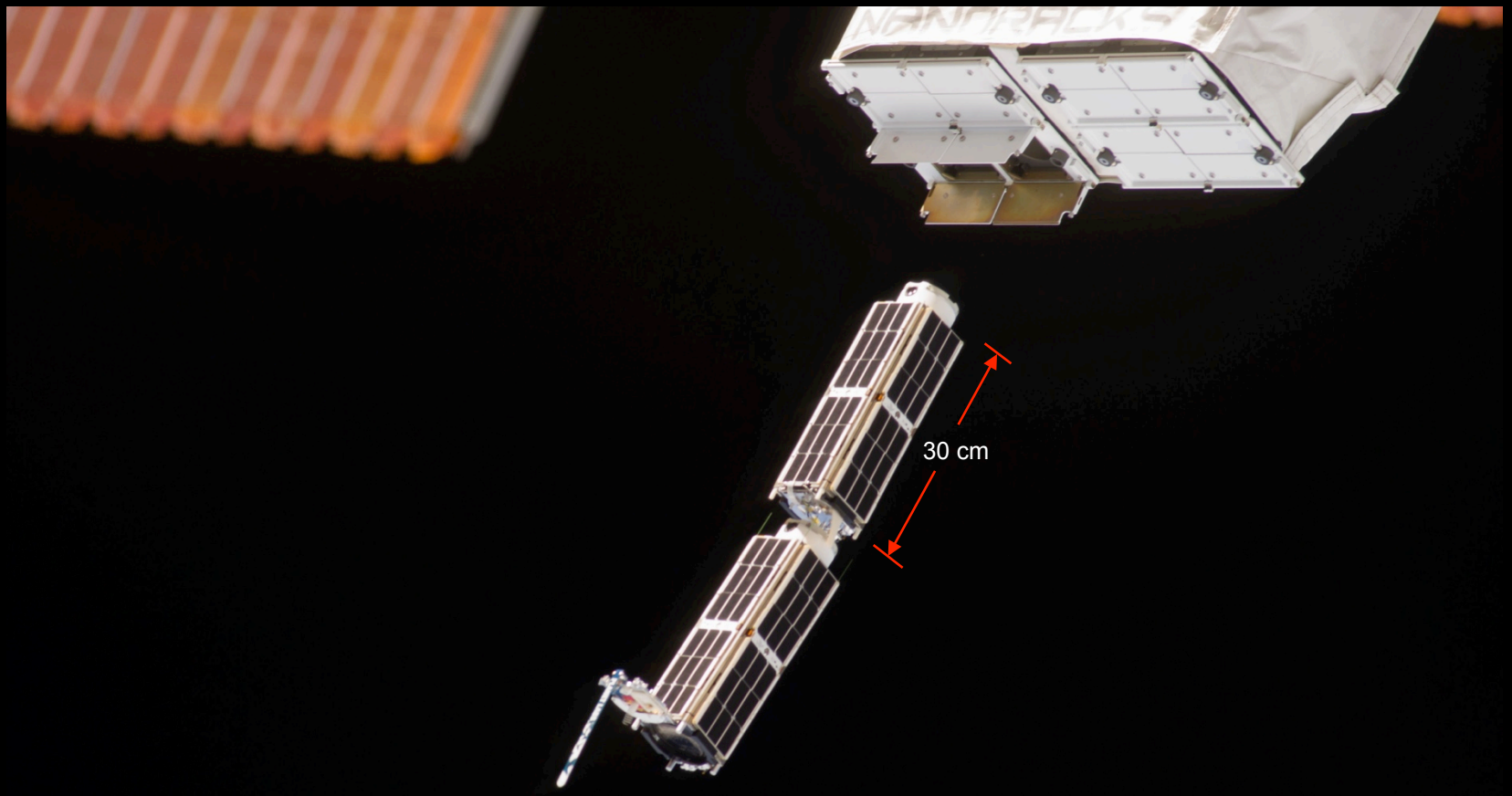
Satellite Class	Mass Range
Minisatellite	100 or higher
Microsatellite	10 – 100 kg
Nanosatellite	1 – 10 kg
Picosatellite	10 g - 1 kg
Femtosatellite	1 – 10 g

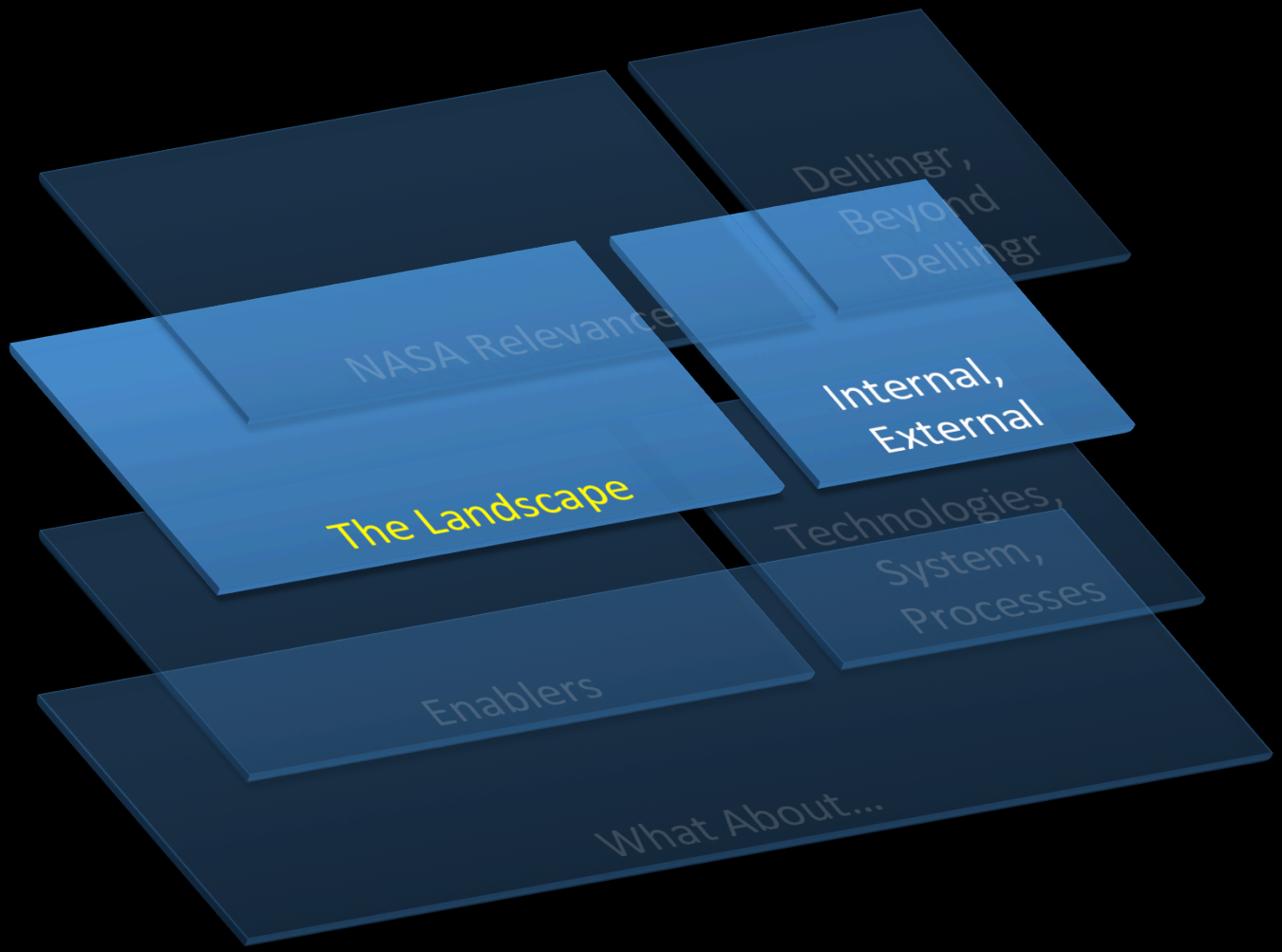
A CubeSat starts as just an empty box. Its capabilities are limited by the developer’s.

CubeSat Deployment

Standard canisterized system and low cost reduces barriers to flight

CubeSat Deployment




Dellingr,
Beyond
Dellingr
NASA Relevance
Internal,
External
The Landscape
Technologies,
System,
Processes
Enablers
What About...

The Landscape
The Year 2000. (What's a CubeSat???)

INTRODUCTION

"In 2000, there were ten commercial launches licensed by the Federal Aviation Administration (FAA) for revenue that totaled about $625 million. This total represents seven launches from U.S. ranges for commercial and government customer plus three launches by the multinational Sea Launch Venture."

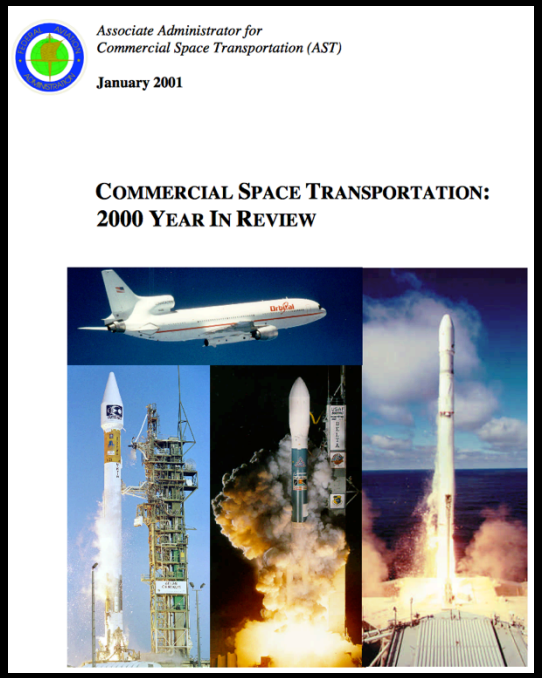
than prior years (39 in 1999 and 41 in 1998). However, the U.S. percentage of commercial launches declined more precipitously. There were seven U.S. commercial launches in 2000, or 20 percent of the world total. The United States captured 38 percent of the commercial launches in 1999 and 54 percent in 1998. Also, the ten launches licensed by the FAA in 2000 were fewer than expected and represented a decrease from prior years (17 in 1999 and 22 in 1998).

Among the ten licensed launches was Boeing's third flight of the Delta 3. The flight was successful and the vehicle deployed a test payload. Lockheed Martin's International Launch Services successfully flew its new Atlas 3A vehicle, which deployed a communications spacecraft for Eutelsat.

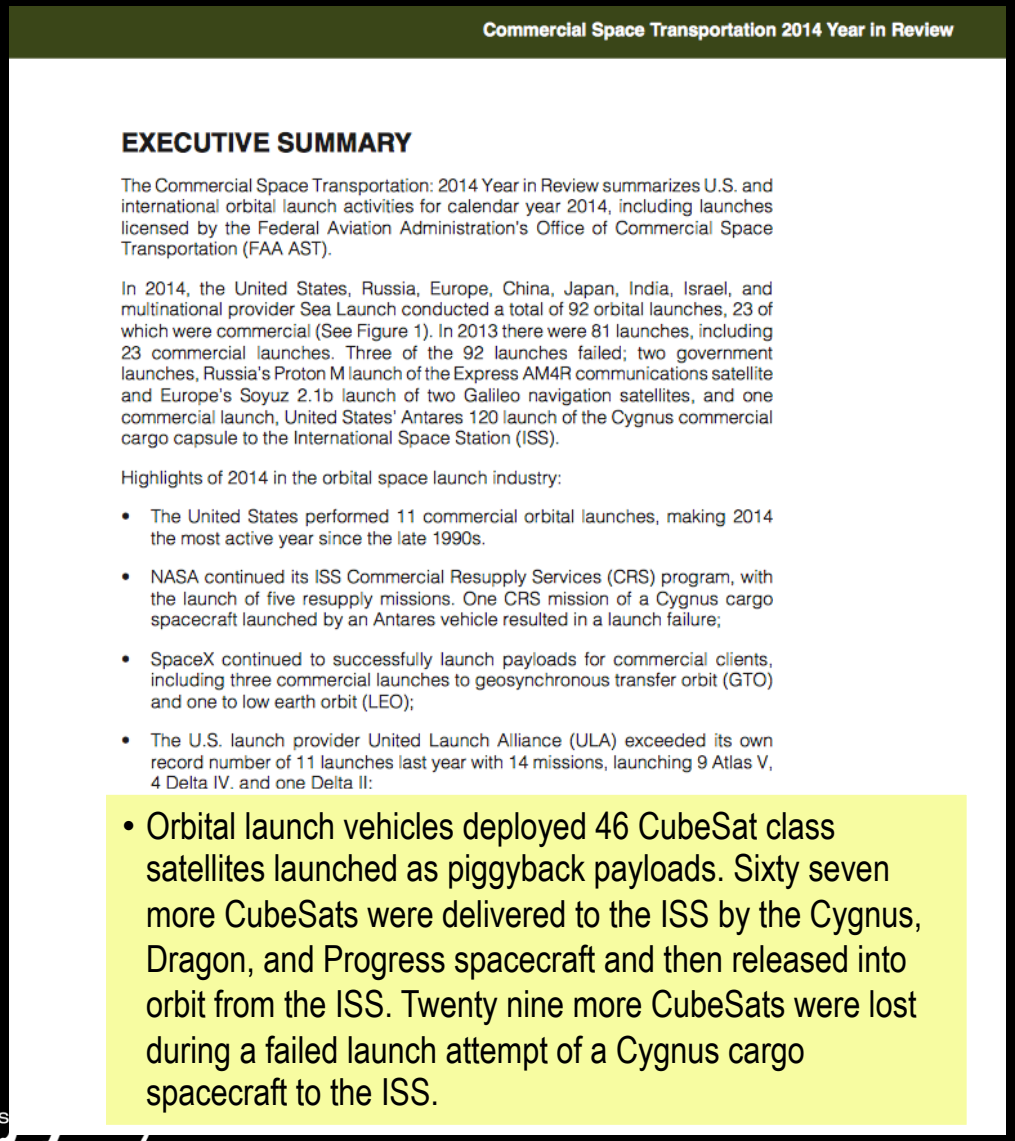
Several new commercial space applications contributed to the worldwide commercial launch total. Three Proton rockets deployed satellites for Sirius Satellite Radio, a company that will offer direct radio broadcast services to the United States. Three Soyuz vehicles carried cargo and a cosmonaut crew to the Mir space station with private financing from MirCorp, a company that planned commercial development of the station through tourist flights.

Commercial Space Transportation: 2000 Year in Review summarizes U.S. and international launch activities for calendar year 2000 and provides a historical look at the past five years of commercial launch activities. This report has three parts:

- 2000 FAA-Licensed Commercial Activity
- 2000 Worldwide Launch Activity
- Five-Year Space Transportation Trends



The Landscape
The Year 2014



Commercial Space Transportation 2014 Year in Review

EXECUTIVE SUMMARY

The Commercial Space Transportation: 2014 Year in Review summarizes U.S. and international orbital launch activities for calendar year 2014, including launches licensed by the Federal Aviation Administration's Office of Commercial Space Transportation (FAA AST).

In 2014, the United States, Russia, Europe, China, Japan, India, Israel, and multinational provider Sea Launch conducted a total of 92 orbital launches, 23 of which were commercial (See Figure 1). In 2013 there were 81 launches, including 23 commercial launches. Three of the 92 launches failed; two government launches, Russia's Proton M launch of the Express AM4R communications satellite and Europe's Soyuz 2.1b launch of two Galileo navigation satellites, and one commercial launch, United States' Antares 120 launch of the Cygnus commercial cargo capsule to the International Space Station (ISS).

Highlights of 2014 in the orbital space launch industry:

- The United States performed 11 commercial orbital launches, making 2014 the most active year since the late 1990s.
- NASA continued its ISS Commercial Resupply Services (CRS) program, with the launch of five resupply missions. One CRS mission of a Cygnus cargo spacecraft launched by an Antares vehicle resulted in a launch failure;
- SpaceX continued to successfully launch payloads for commercial clients, including three commercial launches to geosynchronous transfer orbit (GTO) and one to low earth orbit (LEO);
- The U.S. launch provider United Launch Alliance (ULA) exceeded its own record number of 11 launches last year with 14 missions, launching 9 Atlas V, 4 Delta IV, and one Delta II;

- Orbital launch vehicles deployed 46 CubeSat class satellites launched as piggyback payloads. Sixty seven more CubeSats were delivered to the ISS by the Cygnus, Dragon, and Progress spacecraft and then released into orbit from the ISS. Twenty nine more CubeSats were lost during a failed launch attempt of a Cygnus cargo spacecraft to the ISS.

The Landscape
The Year 2014

Federal Aviation Administration's Office of Commercial Space Transportation

NON-U.S. ORBITAL LAUNCH ACTIVITY

The following section of the report highlights non-U.S. launch activity on a country-by-country basis.

Russia

In 2014, there were 32 Russian launches. Thirty-one of these were successful, one Proton M failed. Eight launches were with Proton vehicles and 18 with Soyuz vehicles. Dnepr and Rockot performed two launches each. One mission was launched with Strela. The new Angara A5 heavy class launch vehicle performed a successful test launch of a dummy payload to GEO from a northern Russia launch site Plesetsk; this test flight was preceded by a suborbital test launch of a lighter Angara version. Twenty-one of the missions launched from Baikonur Cosmodrome, and nine missions launched from Plesetek. Two Dnepr launches were condicted from Dombarovskiy Air Base. Four launches were commercial and 28 were non-commercial. The non-commercial missions are detailed below.

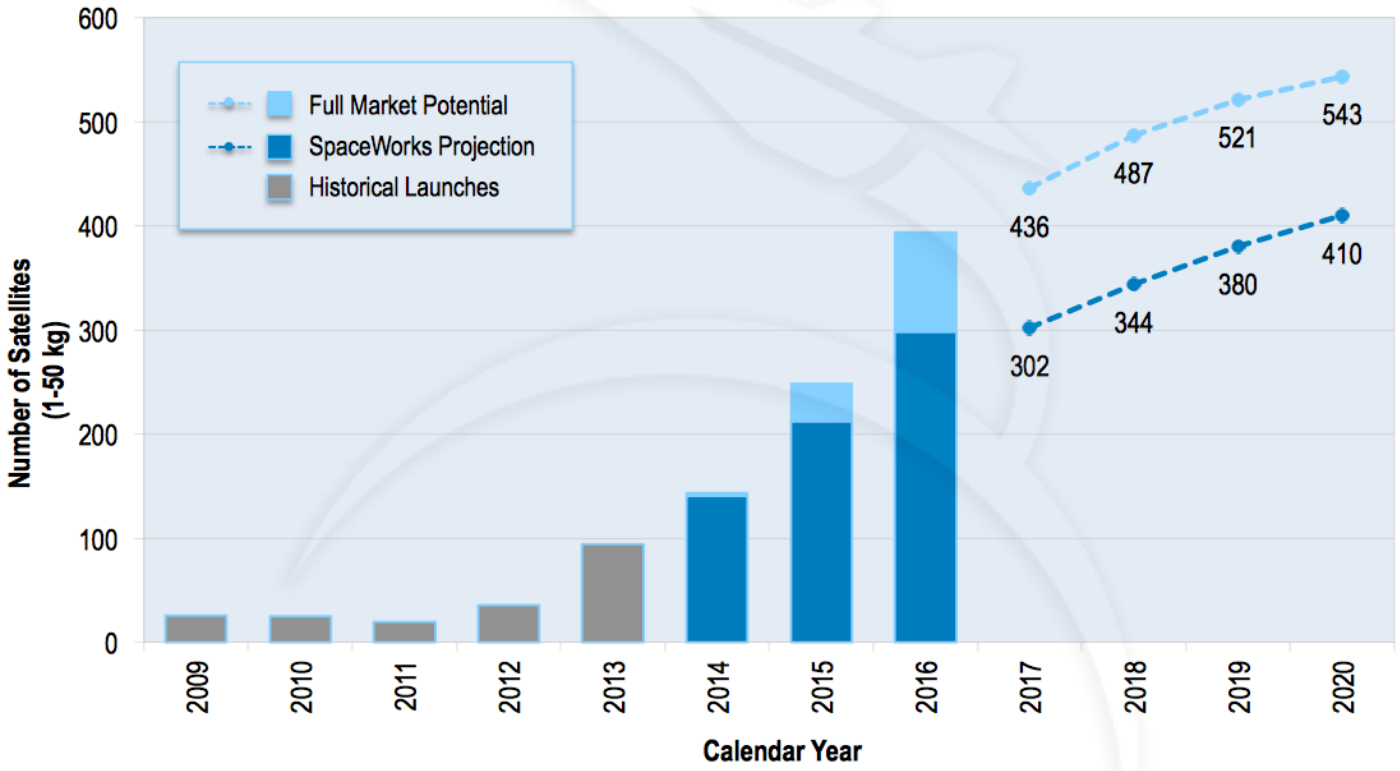
- Eight Soyuz launches were dedicated ISS missions, involving four Progress M cargo missions and four Soyuz spacecraft crew exchange missions.
- Nine launches were performed in the interest of the Russian military. A Proton vehicle launched a GEO communications satellite Olymp K. Six Soyuz vehicles launched three Glonass series navigation satellites and three intelligence satellites. A Rockot vehicle launched three Cosmos series store-and-forward communications satellites. One Strela launch vehicle launched Kondor E1, an imagery intelligence satellite.
- Russia conducted 10 launches for civil purposes, that were not related to the ISS. Four Proton vehicles launched six GEO communications satellites (two of the launches were dual manifest), one launch, intended to deploy Express AM4R, resulted in a failure. Four Soyuz vehicles launched four primary payloads, including two remote sensing satellites, a weather, and a science payload. The launch of the Meteor 3M N2 weather satellite also carried five microsats as piggyback payloads. Rockot launched three Gonets series store-and-forward communications satellites. The new Angara A5 heavy class launch vehicle performed a successful test launch of a dummy payload to GEO

- KazEoSat 2 was launched with 36 secondary payloads, … and 35 microsatellites, most of them CubeSats. ASNARO 1 was launched with four Japanese university microsatellites.

The Landscape
An Upward Trend

Nano/Microsatellite Launch History and Projection (1 - 50 kg)

Projections based on announced and future plans of developers and programs indicate between 2,000 and 2,750 nano/microsatellites will require a launch from 2014 through 2020



Ref: 2014 Nano/ Microsatellite Market Assessment, SpaceWorks Enterprises, Inc.

Smallsats Finding New Applications

By Frank Morring, Jr.
Aviation Week & Space Technology, Aug 2013

Small, low-cost satellites are coming into their own as a niche industry serving commercial and government markets, building on the free development work provided by a generation of engineering students at places like California Polytechnic State University and Morehead State University in Kentucky.

It is now clear that smallsat technology is leapfrogging beyond the classroom. No longer just a hands-on teaching tool, miniature spacecraft are in serious development as weather monitors, Earth- and space-observation telescopes and a host of scientific probes.

“The genesis for a lot of the work has been in the universities, but we're now coming to a kind of a cusp, or a knee in the curve,” says Charles S. (Scott) MacGillivray, president of Tyvak Nano-Satellite Systems, a two-year-old startup that is gaining serious traction in the market for cubesat components, engineering services and launch integration. “We can start saying 'hey, we can do real missions with these.'”

Presentations at the 27th annual Small Satellite Conference at Utah State University here last week underscore MacGillivray's point.

During last year's conference Tyvak signed a $13.5 million NASA technology-development contract for the Cubesat Proximity Operations Demonstration (CPOD) mission, which will fly two 3U cubesats (each one comprising three 10-cm “cubes” that are each counted as one “U”) to orbit. Once there, the two tiny spacecraft will use a multi-thruster cold-gas propulsion system to fly a choreographed pattern around each other before docking, accomplishing the task with imagery, a cross-linked GPS signal and sophisticated software running on high-performance onboard processors.

Although most of the small-satellite and miniature instruments covered at this year's conference are still in development, the range of topics suggests the next few years will see a dramatic increase in “real missions” conducted with small spacecraft. Among them are “High-performance Spectroscopic Observation from a Smallsat;” “Star Tracker on a Chip;” “Simultaneous Multi-Point Space Weather Measurements using the Low-Cost EDSN CubeSat Constellation;” “Cicero—A Distributed Small Satellite Radio Occultation Pathfinder Mission,” and “TacSat-4: Military Utility in a Small Communication Satellite.”

Until recently, SmallSats were considered too limited for meaningful work in space. Designers have been spending a lot of time working on ways to enhance the capabilities, and the payoff is starting to appear. Presenters from the Space Dynamics Laboratory here and NASA Ames Research Center in Mountain View, Calif., displayed dramatically different ways to fold a useful Earth-observation or astronomical telescope into CubeSats for deployment on orbit. Miniature atmospheric sounders and other weather instruments were hot, as were propulsion systems…

SPACENEWS

Spire Raises $40 Million For Weather Satellite Constellation

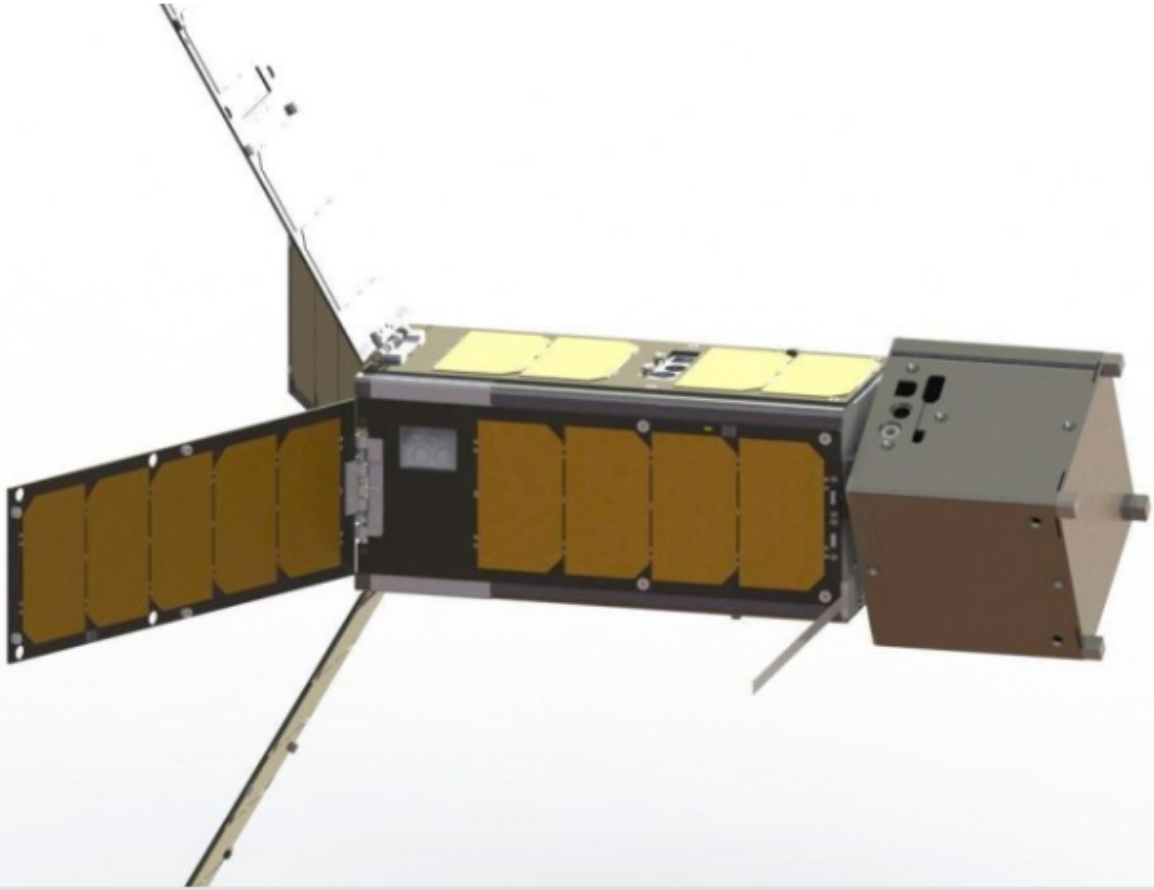
by Jeff Foust — June 30, 2015

Spire plans to launch 20 of these 3U cubesats by the end of 2015, and have more than 100 in orbit by the end of 2017. Credit: Spire

WASHINGTON — Spire, a company developing a constellation of cubesats to provide weather data to commercial and government customers, announced June 30 it has raised $40 million to complete work on the satellites and begin launching them later this year.

NOAA Cubesat Caught in Crossfire Between Congress, White House

by **Dan Leone** — June 25, 2015

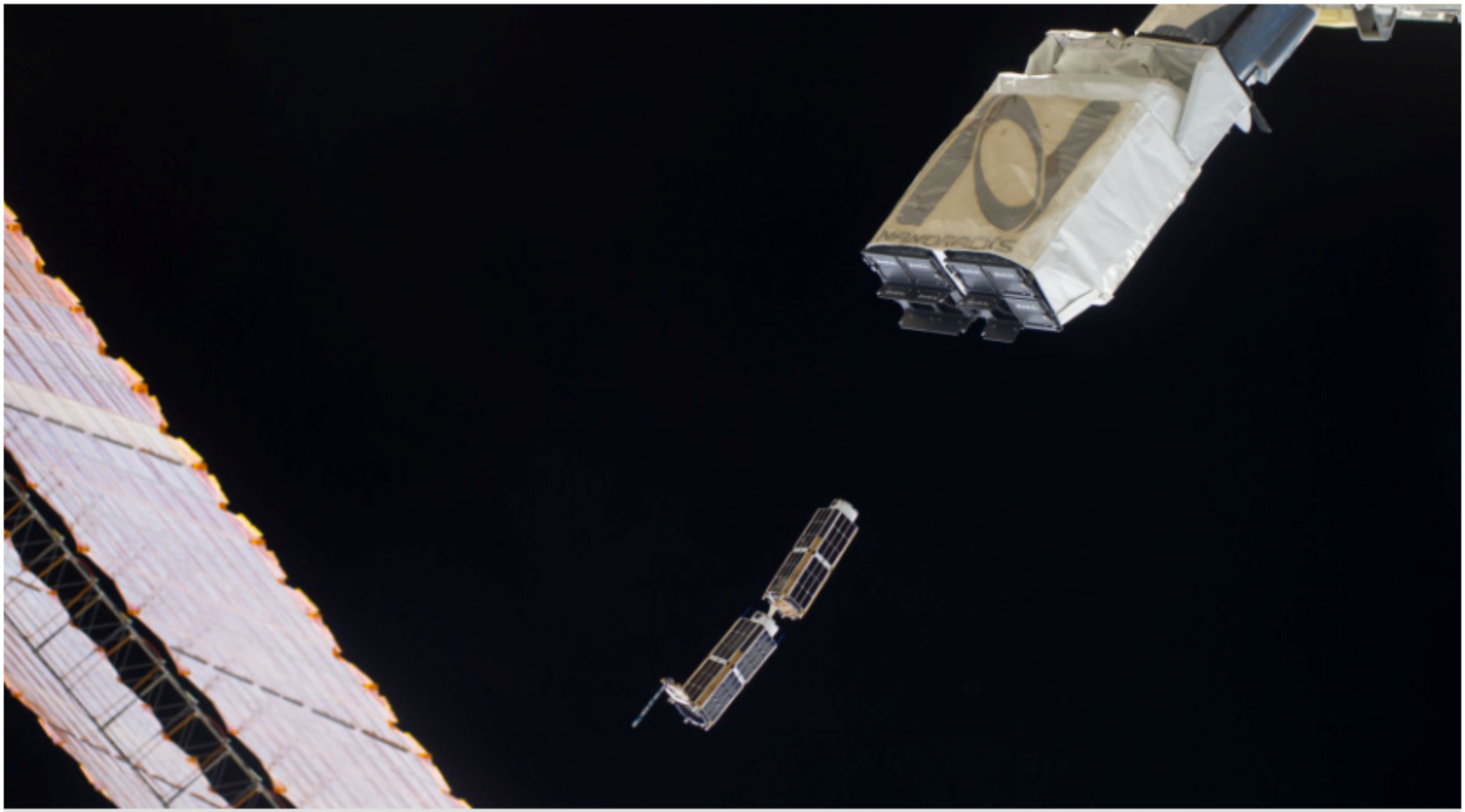


The Microsized Microwave Atmospheric Satellite, pictured here, launched from ISS in March and is similar to another pathfinder cubesat NOAA wants to launch in 2016. However, lack of congressional buy-in during the latest budget cycle has cast doubt on the 2016 launch. Credit: E. Peters, Massachusetts Institute of Technology

WASHINGTON — The National Oceanic and Atmospheric Administration's plan to launch an experimental weather cubesat in 2016 is in doubt because the agency staked funding for the effort to a program that fared poorly in recent budget bills.

Asteroid-mining Company's 1st Spacecraft Deploys

by **Jonathan Charlton** — July 17, 2015

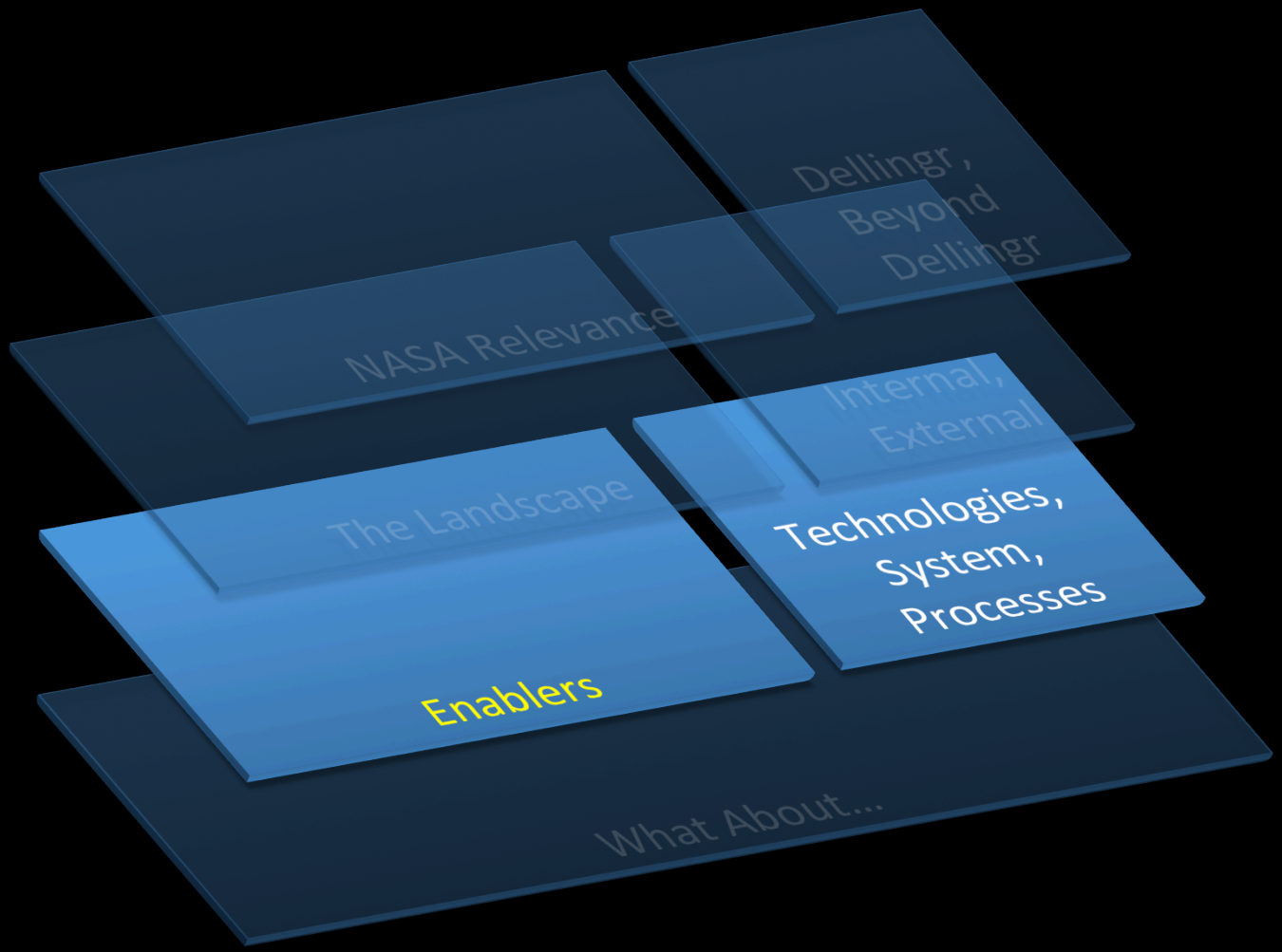


A3R and Centennial-1 (the shorter cubesat) deploy from the NanoRacks dispenser aboard ISS. Credit: NASA

WASHINGTON — The International Space Station deployed a three-unit cubesat from its satellite dispenser for a 90-day mission meant help an aspiring asteroid-mining company make progress toward its long-term goal of extracting resources from space rocks.

Next Step:
Beyond LEO Capabilities

This is not your father's (or mother's) space…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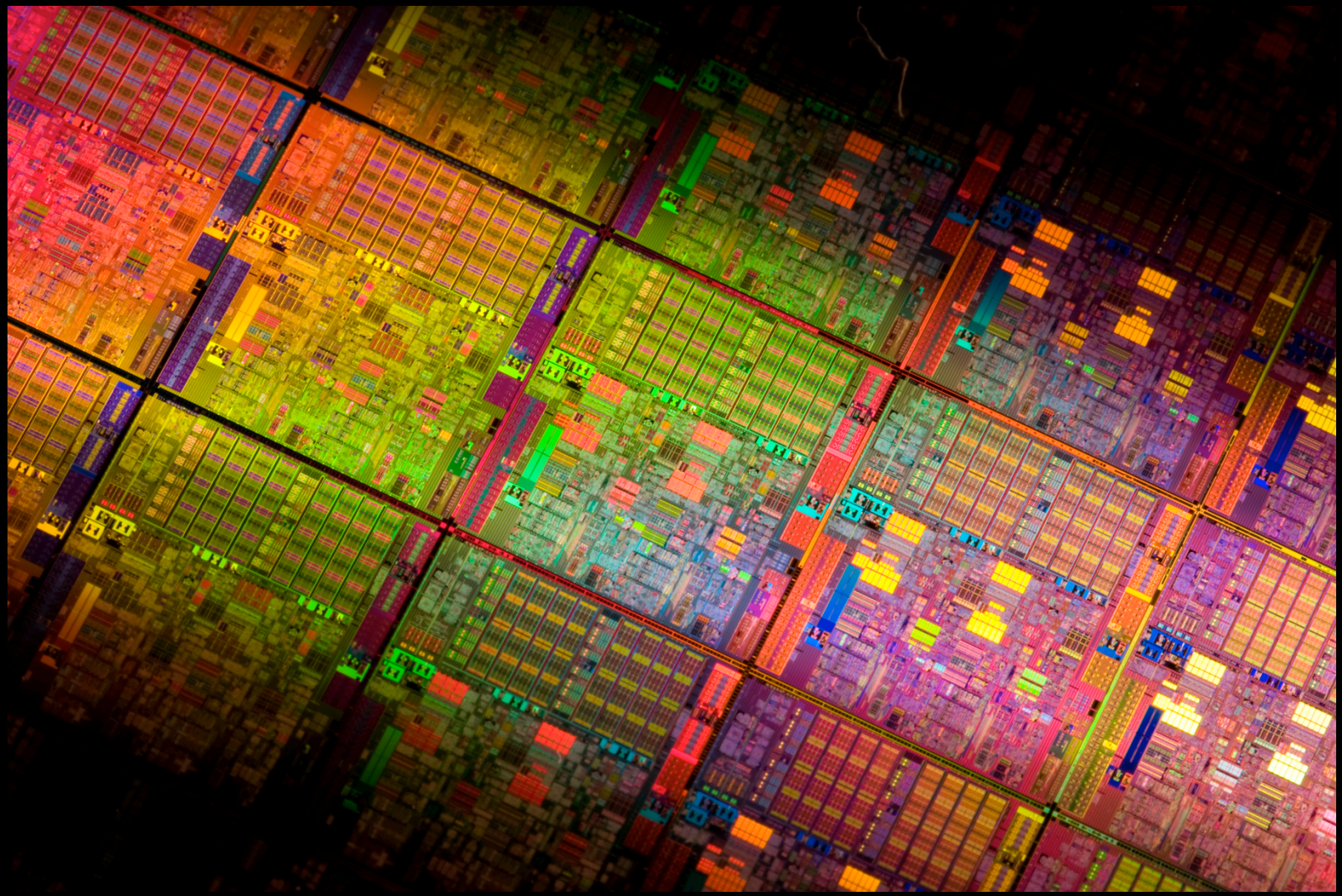
Enablers:
Miniaturized Technology



Enablers:
NASA Small Satellite Technology Program

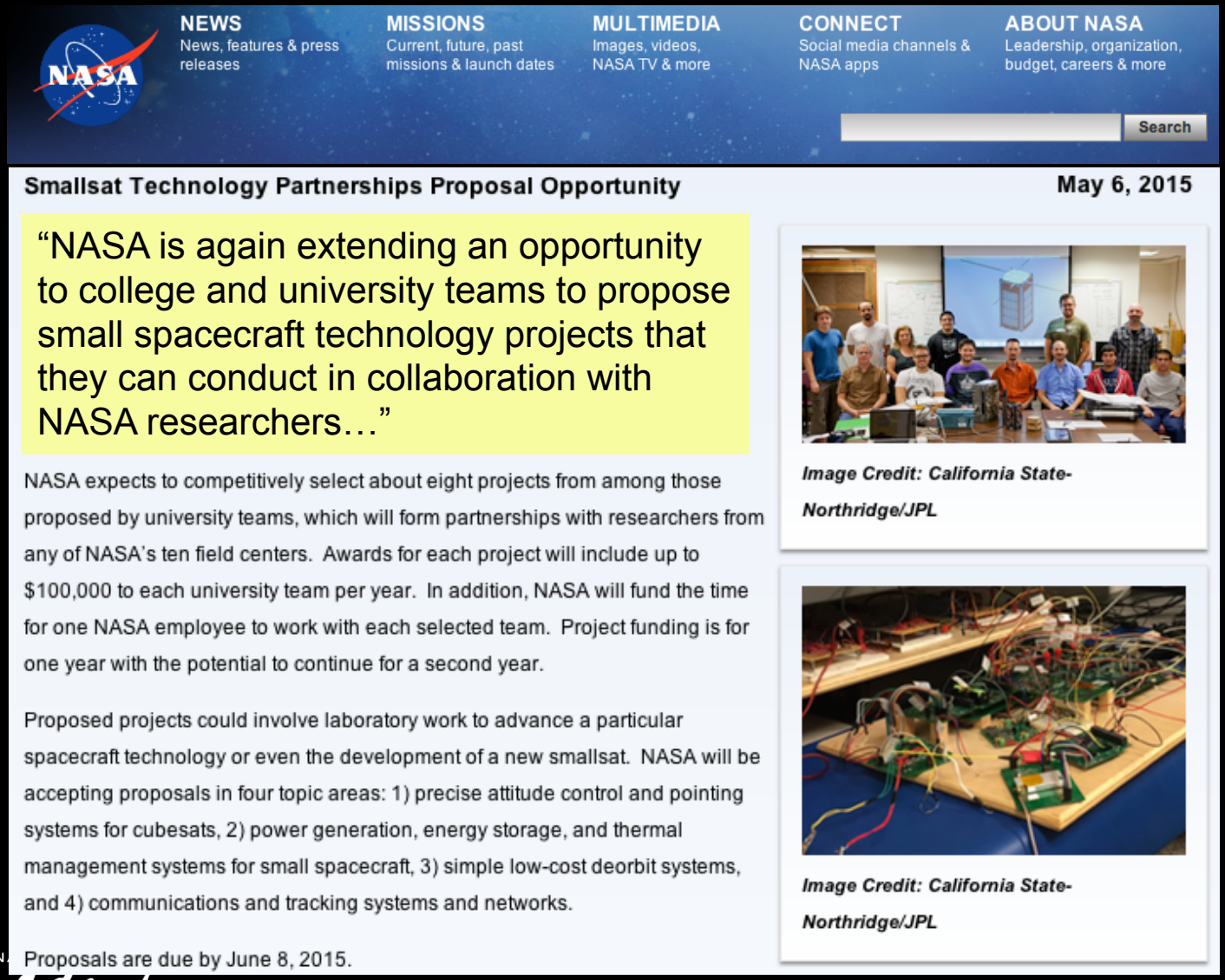
Program Executive: Andrew Petro (HQ)

Objectives:

- Identify and develop new subsystem technologies to enhance or expand the capabilities of small spacecraft.
  TRL 3 to 5
- Demonstrate new technologies, capabilities, and applications for small spacecraft.
  TRL 5 to 7
- Use small spacecraft as low-cost platforms for testing technologies and capabilities with applications for spacecraft and systems of any size.
- Promote the small spacecraft approach as a paradigm shift for NASA and the larger space community.

Ref: Andy Petro/ NASA

Enablers:
A Growing and Innovative Community



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Smallsat Technology Partnerships Proposal Opportunity **May 6, 2015**

"NASA is again extending an opportunity to college and university teams to propose small spacecraft technology projects that they can conduct in collaboration with NASA researchers…"

NASA expects to competitively select about eight projects from among those proposed by university teams, which will form partnerships with researchers from any of NASA's ten field centers. Awards for each project will include up to $100,000 to each university team per year. In addition, NASA will fund the time for one NASA employee to work with each selected team. Project funding is for one year with the potential to continue for a second year.

Proposed projects could involve laboratory work to advance a particular spacecraft technology or even the development of a new smallsat. NASA will be accepting proposals in four topic areas: 1) precise attitude control and pointing systems for cubesats, 2) power generation, energy storage, and thermal management systems for small spacecraft, 3) simple low-cost deorbit systems, and 4) communications and tracking systems and networks.

Proposals are due by June 8, 2015.

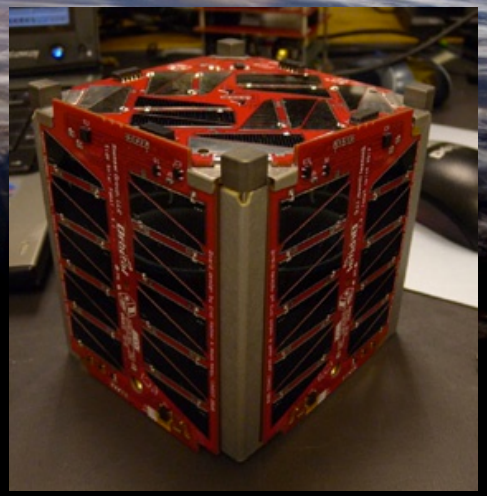
Image Credit: California State-Northridge/JPL

Image Credit: California State-Northridge/JPL

Enablers:
A Growing and Innovative Community

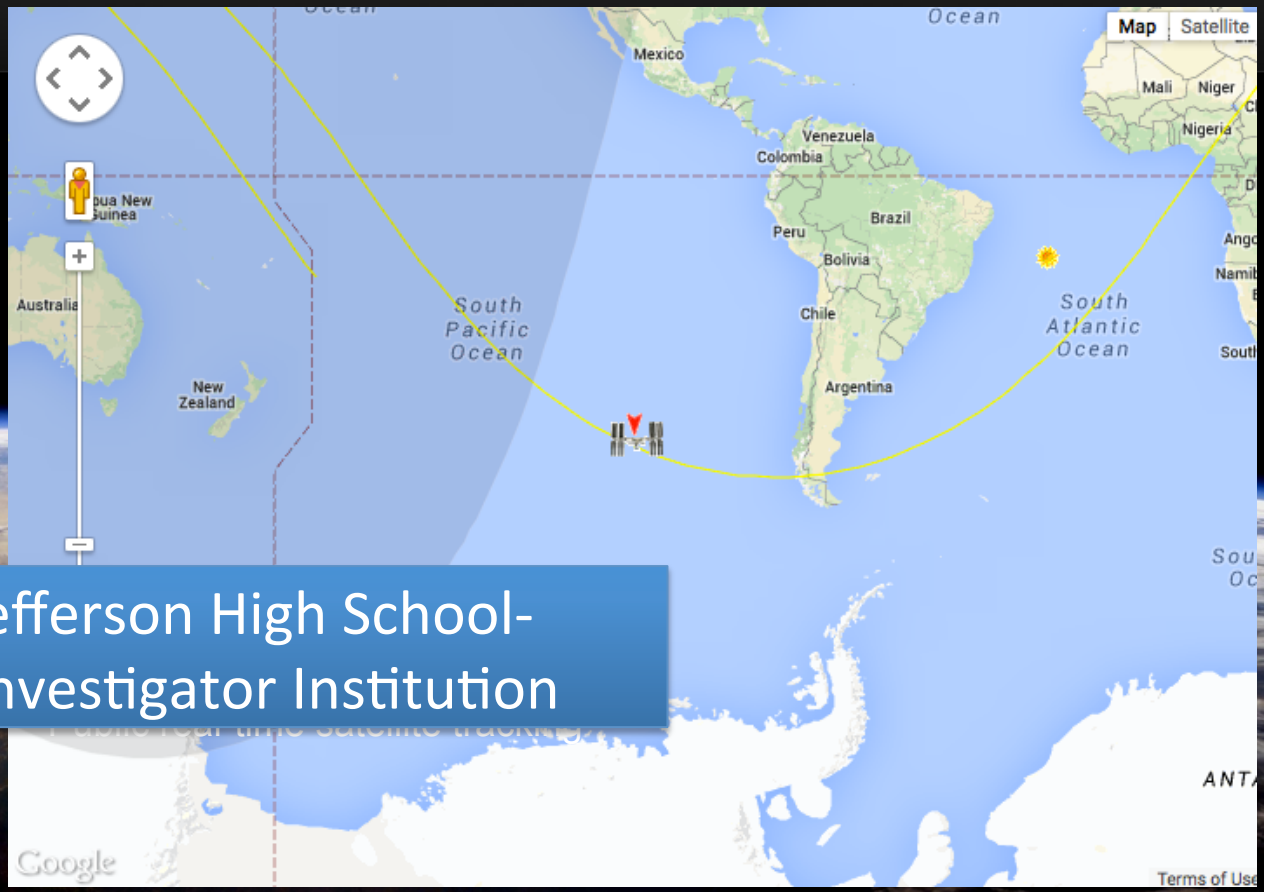
TJ³SAT MISSION PAYLOAD TECHNICAL DOCUMENTATION CONTACT

TJHSST CUBESAT
Orbital
2006 ELaNa-4 2013



Enablers:
A Growing and Innovative Community

TJ³SAT



Thomas Jefferson High School-
Principle Investigator Institution

"We're doing something that a superpower, the Soviet Union, first accomplished," - Alishan Hassan, Former TJ3Sat Student Leader

Enablers:
Advancing Space Systems Technology

Active Project (2014 - 2016)

Ultra-Miniaturized Star Tracker for Small Satellite Attitude Control Project

SBIR/STTR Programs | Space Technology Mission Directorate (STMD)

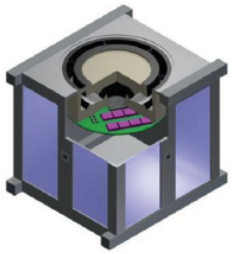
ABSTRACT

Creare and Embry-Riddle Aeronautical University (ERAU) propose to complete the design, development, and testing of an ultra compact star tracker specifically intended for small satellites such as the CubeSat platform. Our design is based on proprietary "folded optics" technology previously developed by ERAU for use in military and commercial optical applications that require a compact footprint and high performance. Furthermore, the design utilizes recent advances in high pixel count CMOS imaging sensor technology. The folded optics design is superior to conventional refractive optics in miniature star trackers because (1) the compact footprint is achieved without sacrificing accuracy; (2) the light-gathering aperture is much greater, leading to better sensitivity; (3) the aperture geometry makes the shielding baffles smaller; and (4) the imaging sensor can be shielded efficiently from cosmic radiation. During the Phase I project, we demonstrated a pointing accuracy of the order of 1 arc second testing a brassboard model of our design. We furthermore completed the design, performed analysis to determine the optimal design parameters, and confirmed the brassboard sensitivity and resolution. In Phase II, we will fabricate the optimized design, test the prototype in the laboratory and in the field, and deliver the prototype to NASA so that NASA can fly the prototype on a NASA high-altitude balloon mission.

ANTICIPATED BENEFITS

To NASA funded missions:

Potential NASA Commercial Applications: Many NASA science missions are exploring the use of pico- and nano-satellites as alternatives to expensive, large satellites. In order to enable their mission profiles, these satellites need high accuracy attitude determination sensors. Our star tracker will enable highly



Creare's Ultraminiaturized Star Tracker Integrated in a 1 U CubeSat

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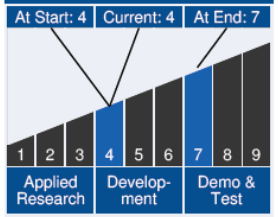
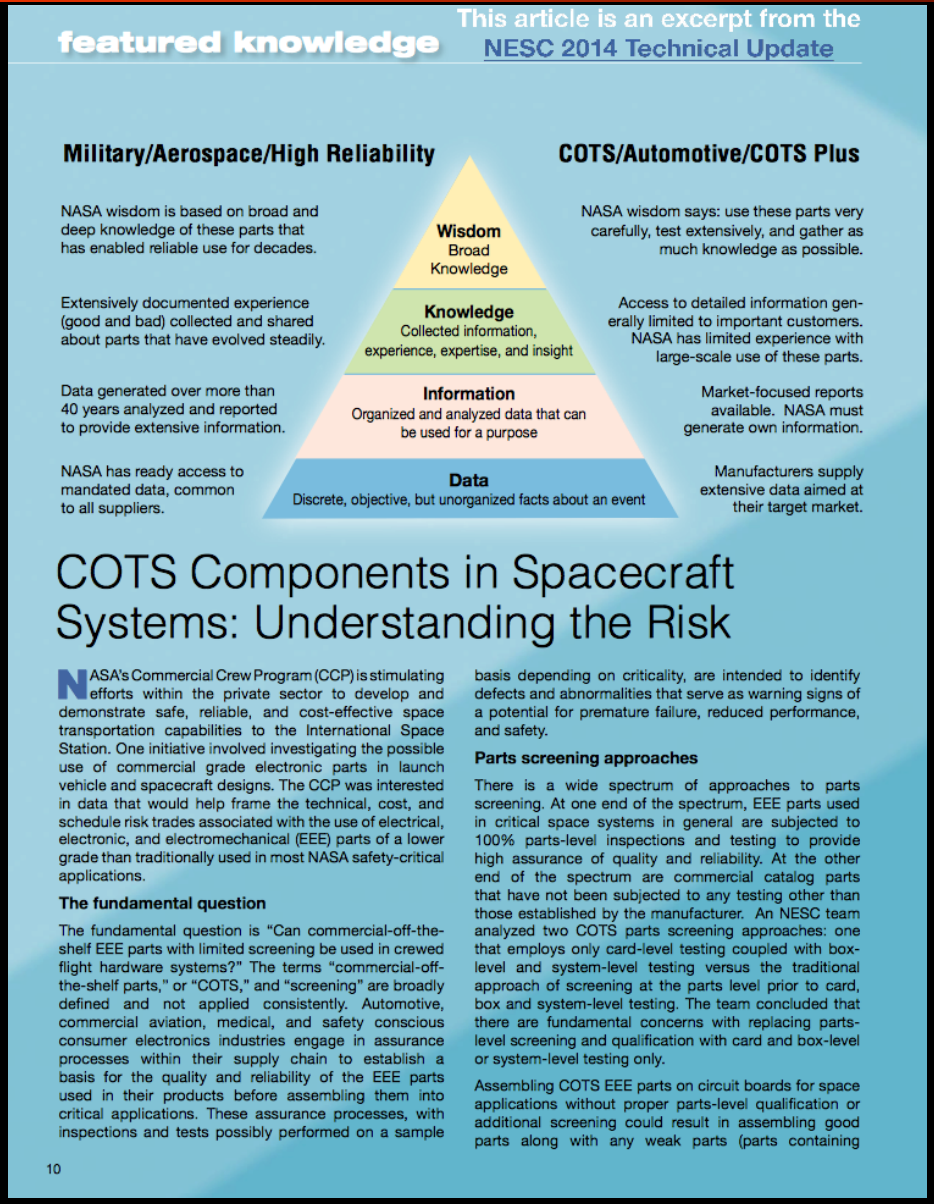
Technology Maturity



Some NASA technology projects are smaller (for example SBIR/STTR, NIAC and Center Innovation Fund), and will have less content than other, larger projects. Newly created projects may not yet have detailed project information.

Enablers:
High Performance Commercial Components



featured knowledge

This article is an excerpt from the NESC 2014 Technical Update

Military/Aerospace/High Reliability

COTS/Automotive/COTS Plus

NASA wisdom is based on broad and deep knowledge of these parts that has enabled reliable use for decades.

NASA wisdom says: use these parts very carefully, test extensively, and gather as much knowledge as possible.

Extensively documented experience (good and bad) collected and shared about parts that have evolved steadily.

Access to detailed information generally limited to important customers. NASA has limited experience with large-scale use of these parts.

Data generated over more than 40 years analyzed and reported to provide extensive information.

Market-focused reports available. NASA must generate own information.

NASA has ready access to mandated data, common to all suppliers.

Manufacturers supply extensive data aimed at their target market.

COTS Components in Spacecraft Systems: Understanding the Risk

NASA's Commercial Crew Program (CCP) is stimulating efforts within the private sector to develop and demonstrate safe, reliable, and cost-effective space transportation capabilities to the International Space Station. One initiative involved investigating the possible use of commercial grade electronic parts in launch vehicle and spacecraft designs. The CCP was interested in data that would help frame the technical, cost, and schedule risk trades associated with the use of electrical, electronic, and electromechanical (EEE) parts of a lower grade than traditionally used in most NASA safety-critical applications.

The fundamental question

The fundamental question is "Can commercial-off-the-shelf EEE parts with limited screening be used in crewed flight hardware systems?" The terms "commercial-off-the-shelf parts," or "COTS," and "screening" are broadly defined and not applied consistently. Automotive, commercial aviation, medical, and safety conscious consumer electronics industries engage in assurance processes within their supply chain to establish a basis for the quality and reliability of the EEE parts used in their products before assembling them into critical applications. These assurance processes, with inspections and tests possibly performed on a sample basis depending on criticality, are intended to identify defects and abnormalities that serve as warning signs of a potential for premature failure, reduced performance, and safety.

Parts screening approaches

There is a wide spectrum of approaches to parts screening. At one end of the spectrum, EEE parts used in critical space systems in general are subjected to 100% parts-level inspections and testing to provide high assurance of quality and reliability. At the other end of the spectrum are commercial catalog parts that have not been subjected to any testing other than those established by the manufacturer. An NESC team analyzed two COTS parts screening approaches: one that employs only card-level testing coupled with box-level and system-level testing versus the traditional approach of screening at the parts level prior to card, box and system-level testing. The team concluded that there are fundamental concerns with replacing parts-level screening and qualification with card and box-level or system-level testing only.

Assembling COTS EEE parts on circuit boards for space applications without proper parts-level qualification or additional screening could result in assembling good parts along with any weak parts (parts containing

10

NASA Goddard SPACE FLIGHT CENTER

Enablers:
Easier Access to Space

New NASA Launch Pad for Small Rockets Is Open for Business

Amy Lynn Thompson, Space.com Contributor | July 31, 2015 02:17pm ET

This computer-aided view shows NASA's historic Launch Pad-39B at the Kennedy Space Center, and the new Small Class Vehicle Launch Pad, called Pad-39C, nearby to the southeast.

Credit: NASA/David Zeiters

View full size image

CAPE CANAVERAL, Fla. — A new NASA launch pad for small rockets has opened for business to customers hoping to send satellites into the final frontier.

Designated as Launch Pad 39C, the new pad at NASA's Kennedy Space Center here is located adjacent to historic Launch Pad 39B — the launch site of both the Apollo and space shuttle programs, and the future homeport for NASA's next big rocket, the Space Launch System. NASA hosted a ribbon cutting for the new launch pad, known officially as the Small Class Vehicle Launch Pad, on July 17.

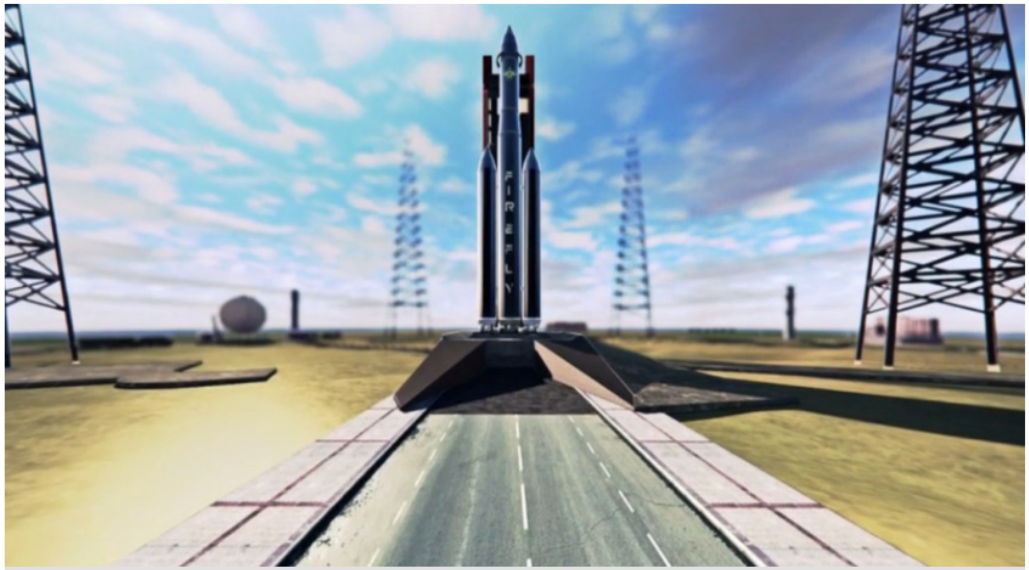
With a current backlog in cubesat research, having a dedicated launch site for small vehicles will enable more of the small satellites to get off the ground. Right now, a smaller satellite has to hitch a ride to orbit as a secondary payload on a large rocket, and the companies cannot control the trajectory or timing of the launch. However, with the opening of a dedicated site servicing smaller rockets, companies will have more control over their launches, NASA officials said.

Enablers:
Easier Access to Space

SPACENEWS

NASA Awards Contracts for Dedicated Cubesat Launches

by Jeff Foust — October 14, 2015



Firefly's Alpha rocket. Credit: Firefly Space Systems

WASHINGTON — NASA announced Oct. 14 that it is awarding more than $17 million in contracts for dedicated launches of cubesats to three companies, none of which has placed a single satellite into orbit.

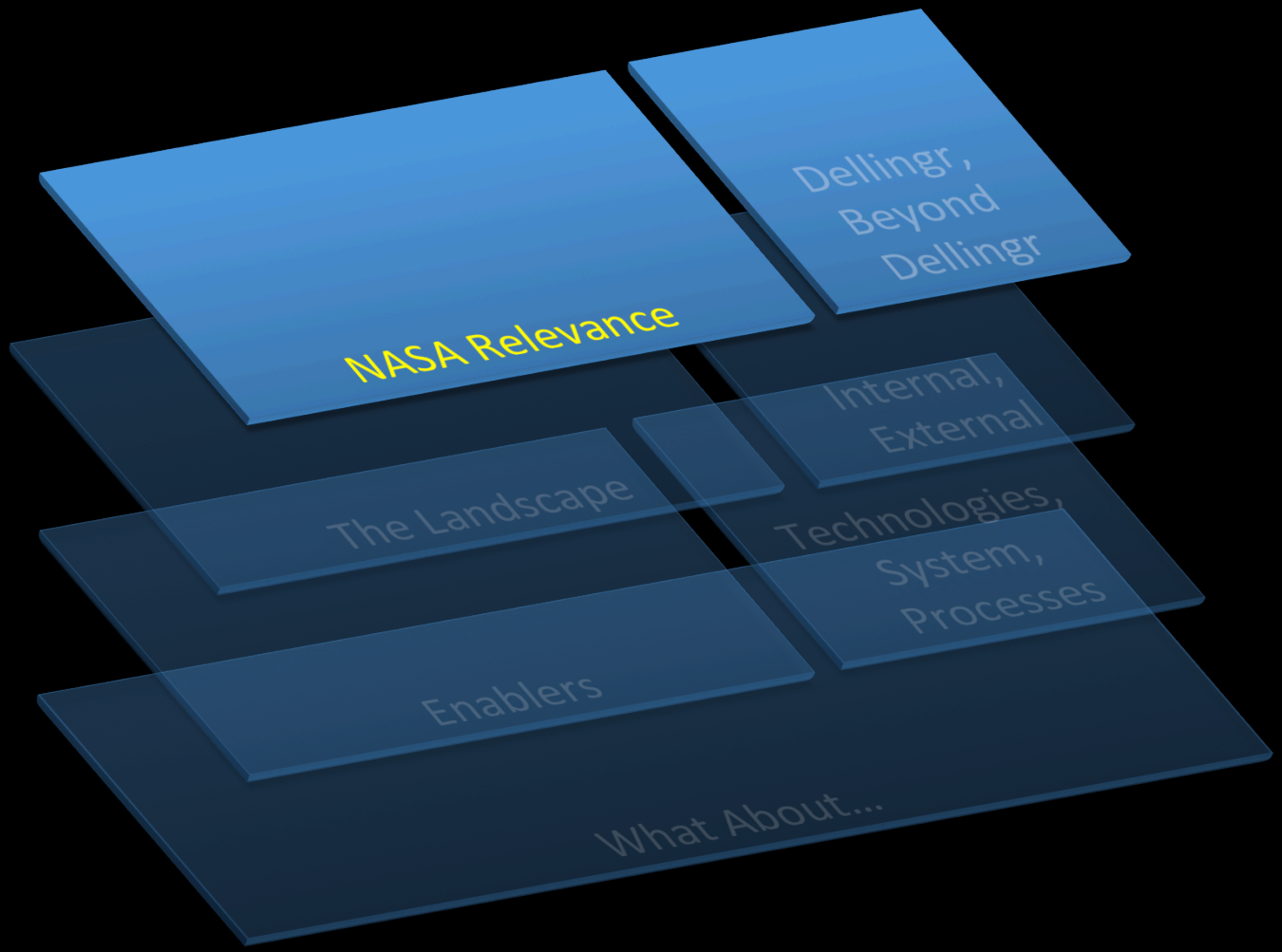
As part of its Venture Class Launch Services program, NASA awarded contracts for one launch each to Firefly Space Systems of Cedar Park, Texas; Rocket Lab USA, headquartered in Los Angeles but with most of its engineering staff based in New Zealand; and Virgin Galactic of Long Beach, California. The combined value of the contracts was $17.1 million.

The program is designed to provide dedicated launches of groups of cubesats. Such satellites today typically fly as secondary payloads, with little control over their orbit and schedule. An existing NASA program, called Education Launch of Nanosatellite, or ELaNa, arranges the launch of NASA and university cubesats on NASA-sponsored missions with excess capacity.

Enablers:
Commercial Investment

Enablers

And this is just the stuff we know about…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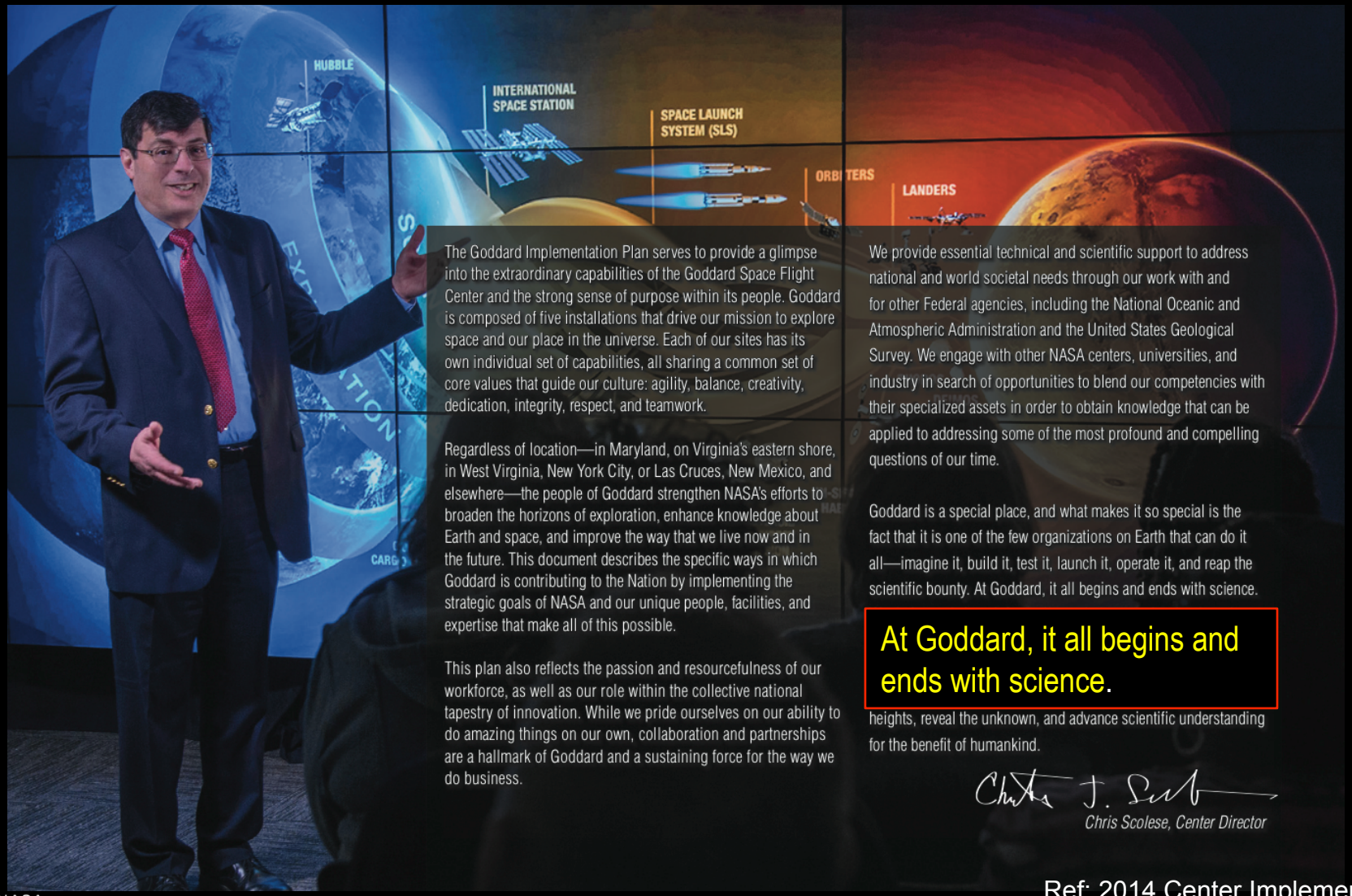
NASA Relevance:
Goddard Context: Science



The Goddard Implementation Plan serves to provide a glimpse into the extraordinary capabilities of the Goddard Space Flight Center and the strong sense of purpose within its people. Goddard is composed of five installations that drive our mission to explore space and our place in the universe. Each of our sites has its own individual set of capabilities, all sharing a common set of core values that guide our culture: agility, balance, creativity, dedication, integrity, respect, and teamwork.

Regardless of location—in Maryland, on Virginia's eastern shore, in West Virginia, New York City, or Las Cruces, New Mexico, and elsewhere—the people of Goddard strengthen NASA's efforts to broaden the horizons of exploration, enhance knowledge about Earth and space, and improve the way that we live now and in the future. This document describes the specific ways in which Goddard is contributing to the Nation by implementing the strategic goals of NASA and our unique people, facilities, and expertise that make all of this possible.

This plan also reflects the passion and resourcefulness of our workforce, as well as our role within the collective national tapestry of innovation. While we pride ourselves on our ability to do amazing things on our own, collaboration and partnerships are a hallmark of Goddard and a sustaining force for the way we do business.

We provide essential technical and scientific support to address national and world societal needs through our work with and for other Federal agencies, including the National Oceanic and Atmospheric Administration and the United States Geological Survey. We engage with other NASA centers, universities, and industry in search of opportunities to blend our competencies with their specialized assets in order to obtain knowledge that can be applied to addressing some of the most profound and compelling questions of our time.

Goddard is a special place, and what makes it so special is the fact that it is one of the few organizations on Earth that can do it all—imagine it, build it, test it, launch it, operate it, and reap the scientific bounty. At Goddard, it all begins and ends with science.

At Goddard, it all begins and ends with science.

heights, reveal the unknown, and advance scientific understanding for the benefit of humankind.

Chris Scolese, Center Director

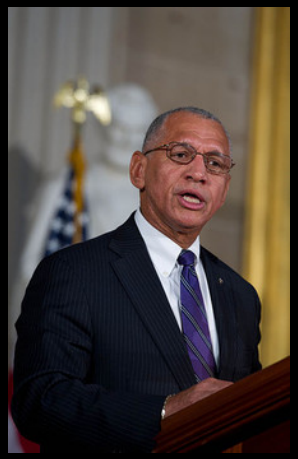
Ref: 2014 Center Implementation Plan

NASA Relevance:
The Fiscal Environment

NASA Relevance:
The Fiscal Environment

"*Flagships are expensive. … We just could not afford to do another one ... We're embarked on an ambitious program of space exploration... We're in tough fiscal times.*"

Charlie Bolden
at the 2013 Goddard Memorial Symposium



NASA Relevance:
The National Research Council (NRC) Investigates

A transformation is ongoing…

- Growing external and internal interest in achieving compelling science via small satellites
- Barriers to space and to achieving credible science are being lowered
- Increasing interest in and growing ability to deploy novel mission architectures (e.g., distributed systems)

***"New Space" ideas**—new players, smaller and less costly platforms (including CubeSats), constellations, and hosted payloads—as well as small PI-led programs (e.g., NASA's Venture-class) and additional use of the ISS platform hold promise to accomplish "more for less".*

Antonio Busalacchi, co-chair,
2017 Earth Science Decadal

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

SPACE STUDIES BOARD
Division on Engineering and Physical Sciences

The Committee on Achieving Science Goals with CubeSats Community Symposium

Ref: Achieving Science Goals with CubeSats symposium, 2-3 September 2015
http://sites.nationalacademies.org/SSB/SSB_167274

NASA Relevance:
NRC Investigation: Earth Science Decadal Planning

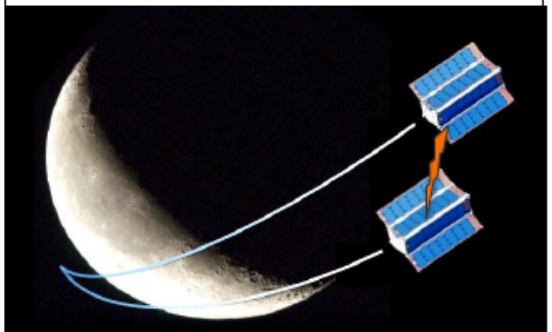
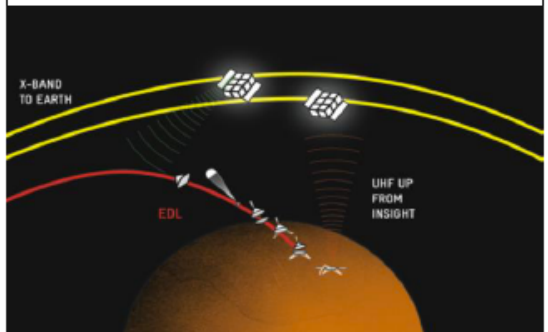
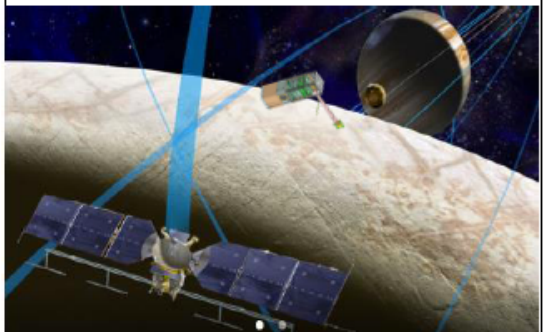
Context for "New Space" Options in the 2017-2027 Decadal Survey for Earth Science and Applications from Space

- Highly constrained agency budgets for the foreseeable future
  - NASA's Earth Science budget under particular scrutiny, but to date has stayed roughly level
  - NOAA has limited budget flexibility; budgets driven by requirements for JPSS and need to avoid a gap in the polar orbiters
  - Congress had asked for Landsat-9 options at significantly reduced cost, but has since backed off; plans for L-9 are to be a L-8 clone at similar cost
- Backlog of missions for NASA from the inaugural survey and those executed are costing 2x or more than forecast by the survey
- NASA has increased responsibility, but not commensurate budget increases, for "continuity" missions formerly assigned to NOAA: total solar irradiance, ocean surface topography, ozone profile, and Earth radiation budget

"New Space" ideas—new players, smaller and less costly platforms (including CubeSats), constellations, and hosted payloads—as well as small PI-led programs (e.g., NASA's Venture-class) and additional use of the ISS platform hold promise to accomplish "more for less."

Ref: Decadal Survey for Earth Science and Applications from Space – ESAS 2017 and the Role of CubeSats in Earth Science, Antonio Busalacchi,

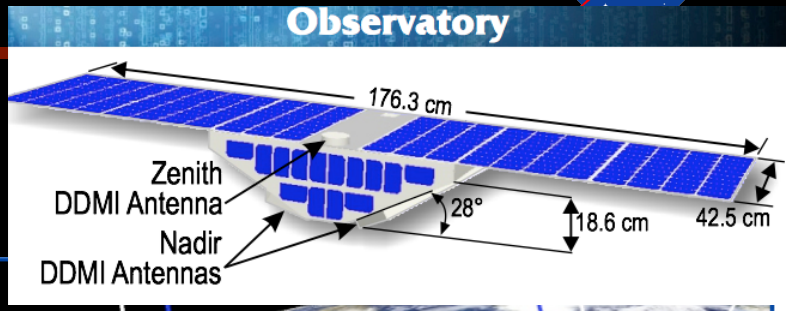
NASA Relevance:
NRC Investigation: Planetary/ JPL Mission Concepts

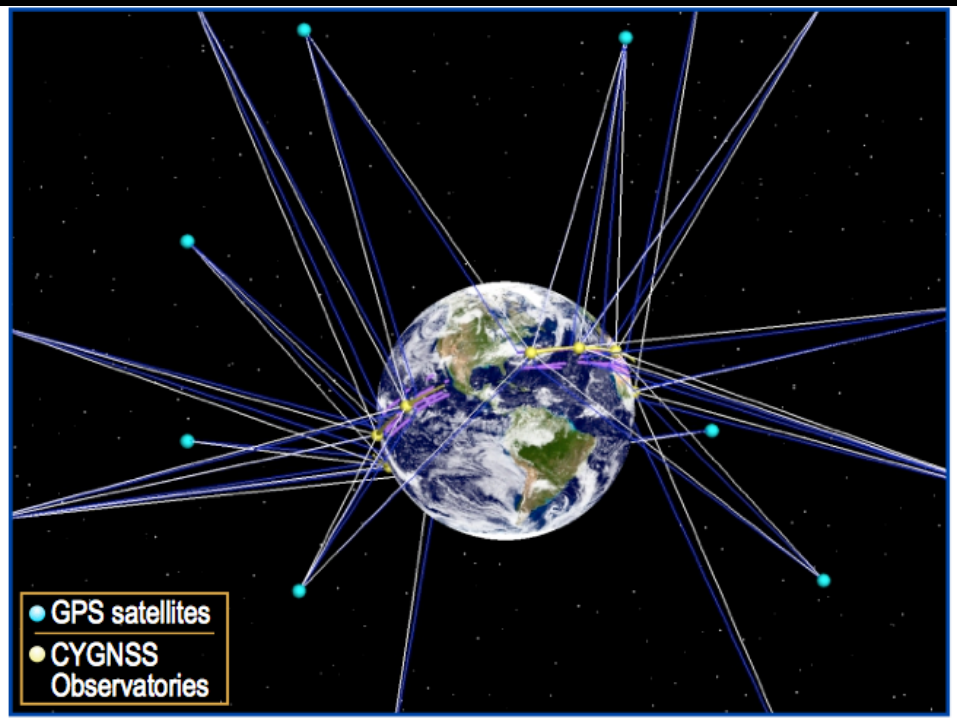
2016 Launch	2016 Launch	In Planning
Technology Demos	**Engineering/Ops**	**Science**
 INSPIRE (NASA/JPL	 MarCO (JPL)	 Europa CubeSats (NASA – Concepts)
Use low-cost spacecraft for technology testing and validation in relevant environment	For example telecom relays during critical operations for lander's entry, descent, and landing; to support a Human crew at Mars; to facilitate teleoperations…	CubeSats that carry primary science, reconnaissance, or opportunistic science investigations; by themselves or as daughtership

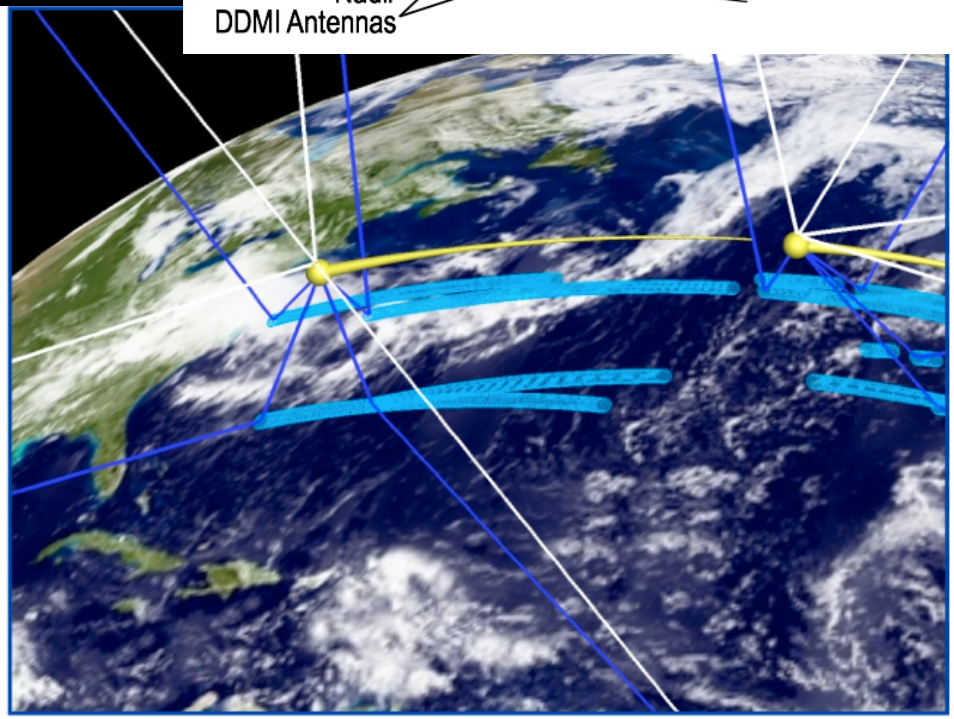
Ref: CubeSat for Planetary Science and Exploration, *Breaking New Grounds,* Julie Castillo-Rogez , JPL

NASA Relevance:
CYGNSS Earth Venture Mission

2016 Launch



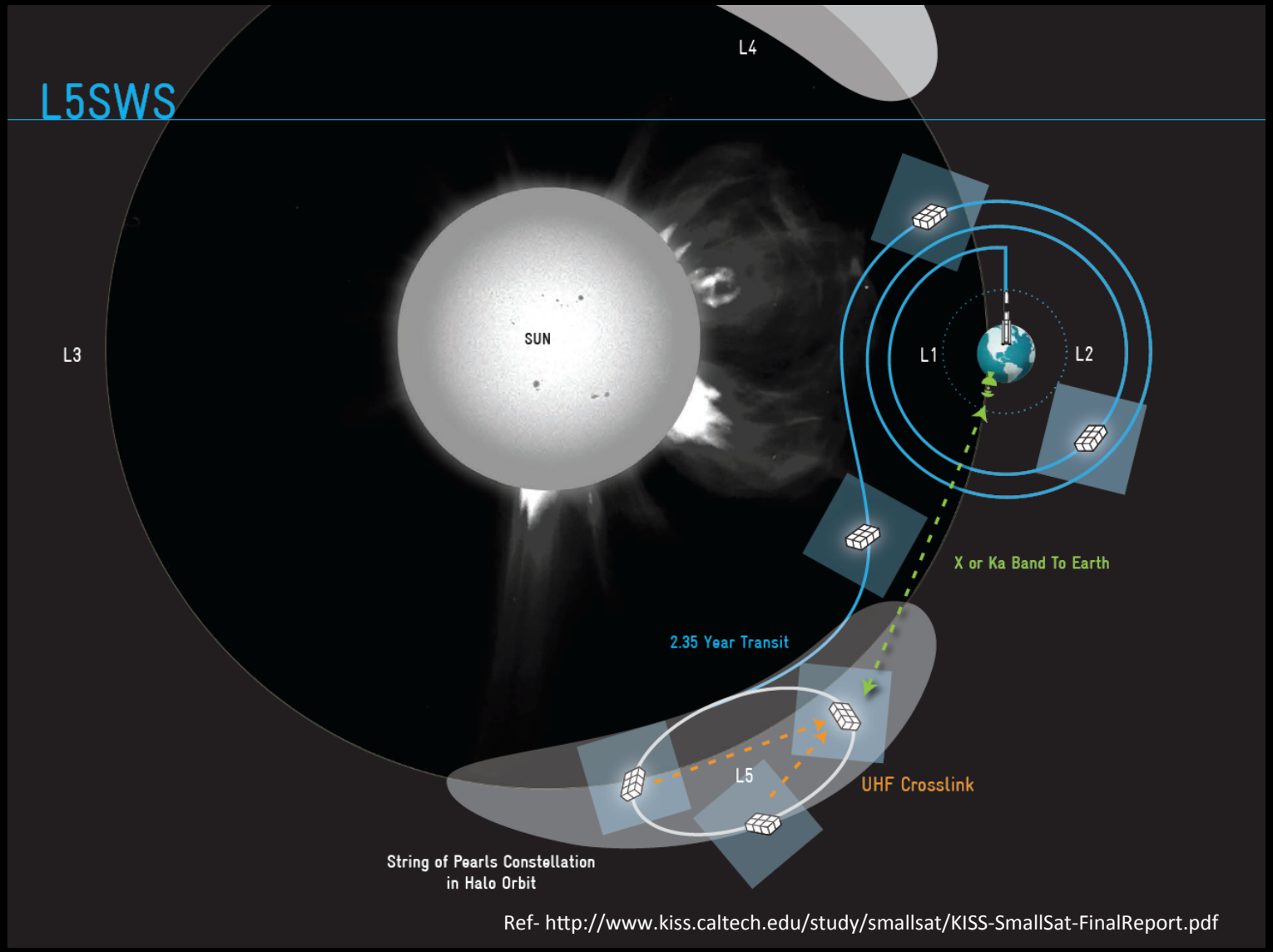




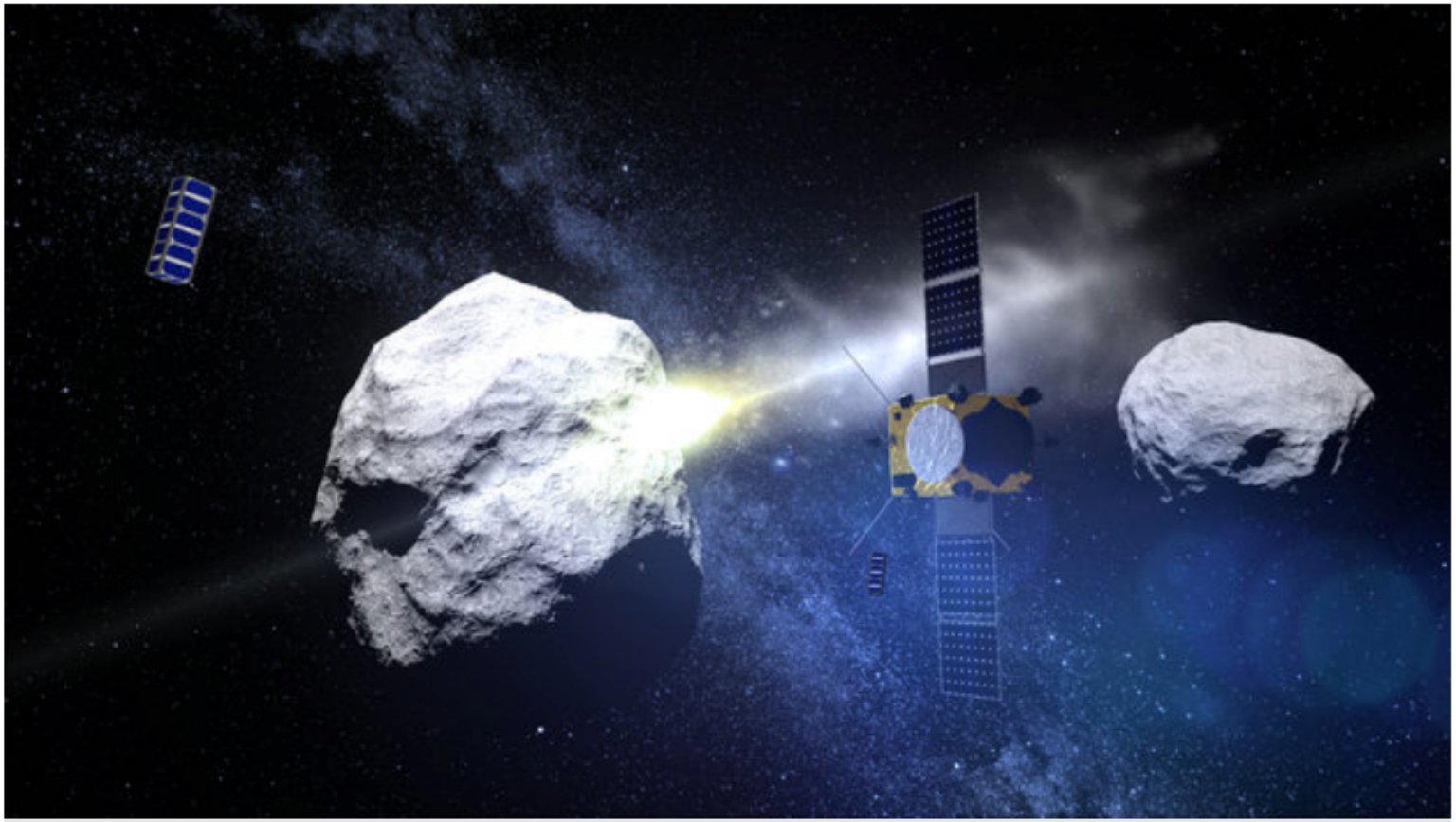
The CYGNSS mission is comprised of 8 Low Earth Orbiting (LEO) spacecraft (S/C) that receive both direct (white lines) and reflected (blue lines) signals from GPS satellites. The direct signals pinpoint LEO S/C positions, while the reflected signals respond to ocean surface roughness, from which wind speed is retrieved. GPS bi-static scatterometry measures ocean surface winds at all speeds and under all levels of precipitation, including TC conditions. In the right figure, instantaneous wind samples are indicated by individual blue circles. Five minutes of wind samples are shown.

Ref: http://clasp.engin.umich.edu/files/articles/CYGNSS_FactSheet_1.pdf

NASA Relevance:
Notional Keck Institute Mission



Ref- http://www.kiss.caltech.edu/study/smallsat/KISS-SmallSat-FinalReport.pdf



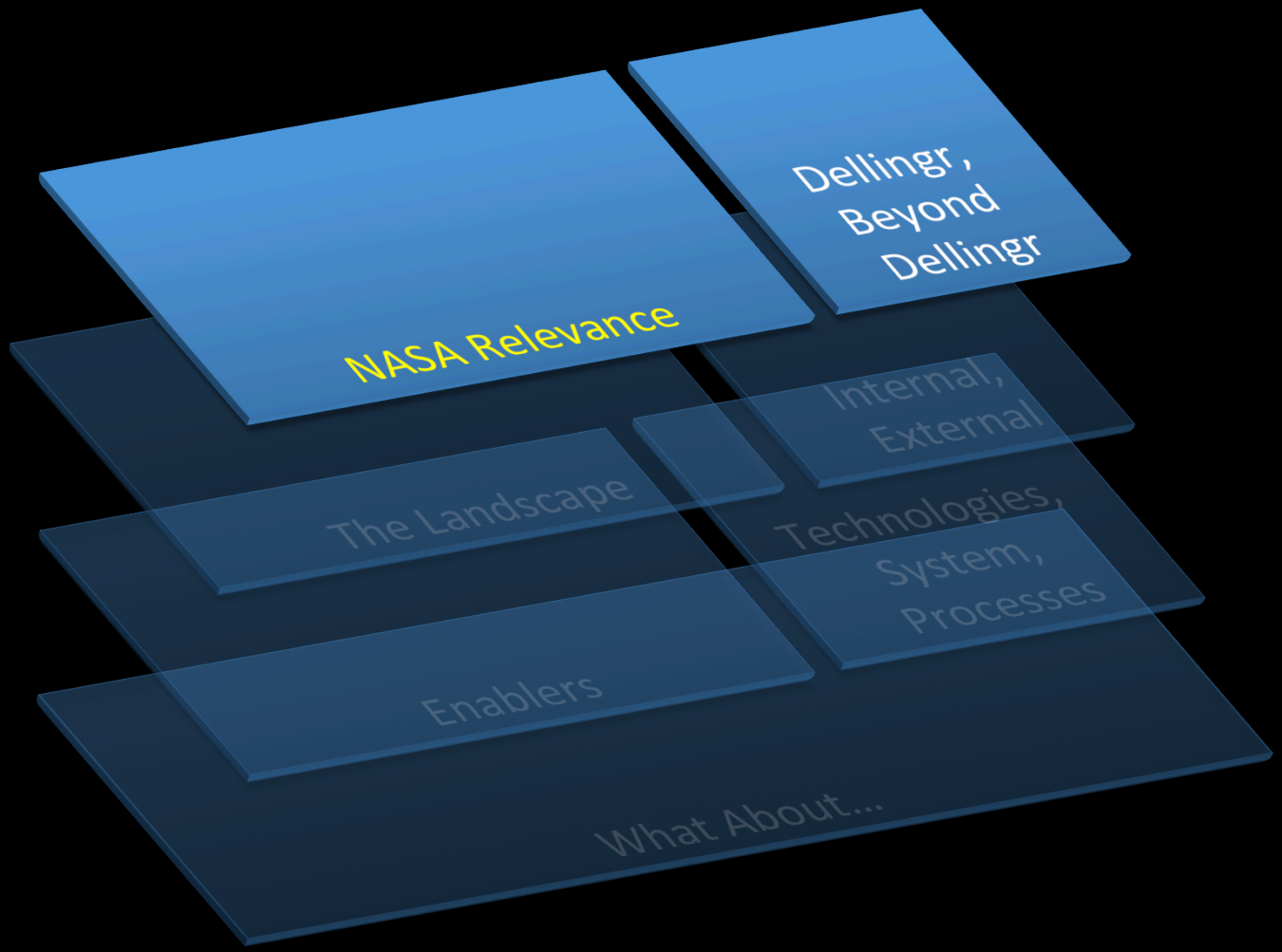
AIM and CubeSats watch impact

CUBESAT COMPANIONS FOR ESA'S ASTEROID MISSION

2 November 2015 The five CubeSat concepts to be studied to accompany ESA's proposed Asteroid Impact Mission into deep space have been selected.

The ideas being looked at include taking a close-up look at the composition of the asteroid surface, measuring the gravity field, assessing the dust and ejecta plumes created during a collision, and landing a CubeSat for seismic monitoring.

Ref: http://www.esa.int/Our_Activities/Space_Engineering_Technology/Asteroid_Impact_Mission/CubeSat_companions_for_ESA_s_asteroid_mission


NASA Relevance
Dellingr, Beyond Dellingr
The Landscape
Internal, External
Enablers
Technologies, System, Processes
What About…

A Path to Compelling Science:
~~AETD Heliophysics CubeSat Skunkworks~~

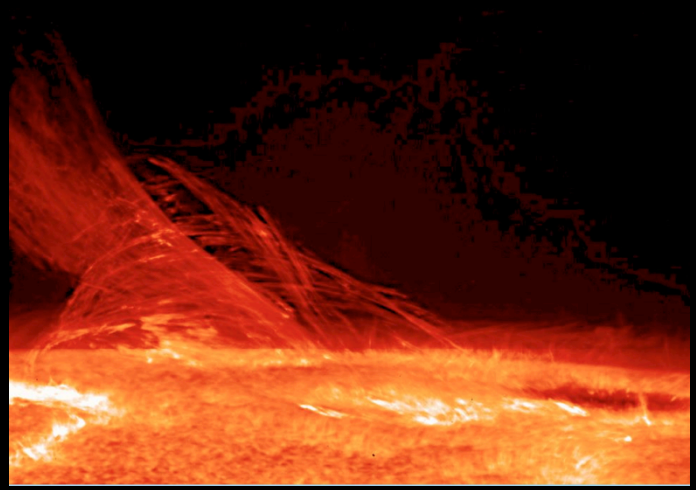
Goddard Reaction:

- Are CubeSats ready for compelling, formidable science?
- What are the issues associated with building them at a "heritage" institution?
- Can we improve reliability while minimally impacting cost?

Challenge: Develop a flight-ready 2-instrument 6U Heliophysics CubeSat with minimal procurement and workforce funding

Dellingr Objectives:

1. Deliver compelling science from two GSFC-developed flagship quality instruments
2. Develop intelligent "lean" end-to-end systems and processes for lower-cost, scalable risk systems
3. Acquire "lessons learned"



A Path to Compelling Science:
Dellingr - Goddard 6U CubeSat Project

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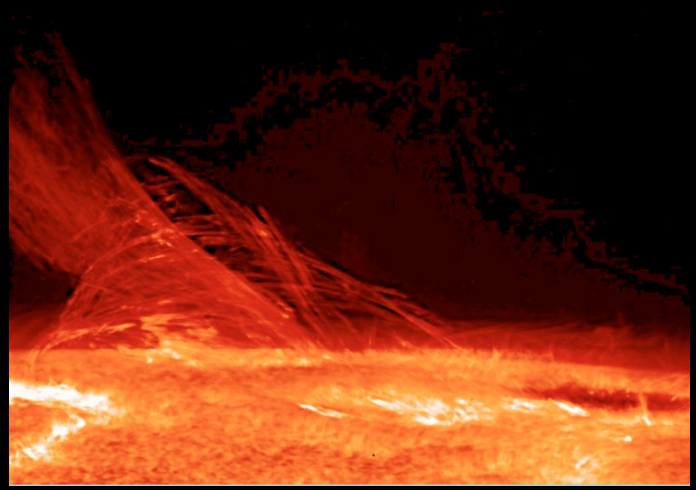


Dellingr:
GSFC-Developed Flagship Quality Instruments

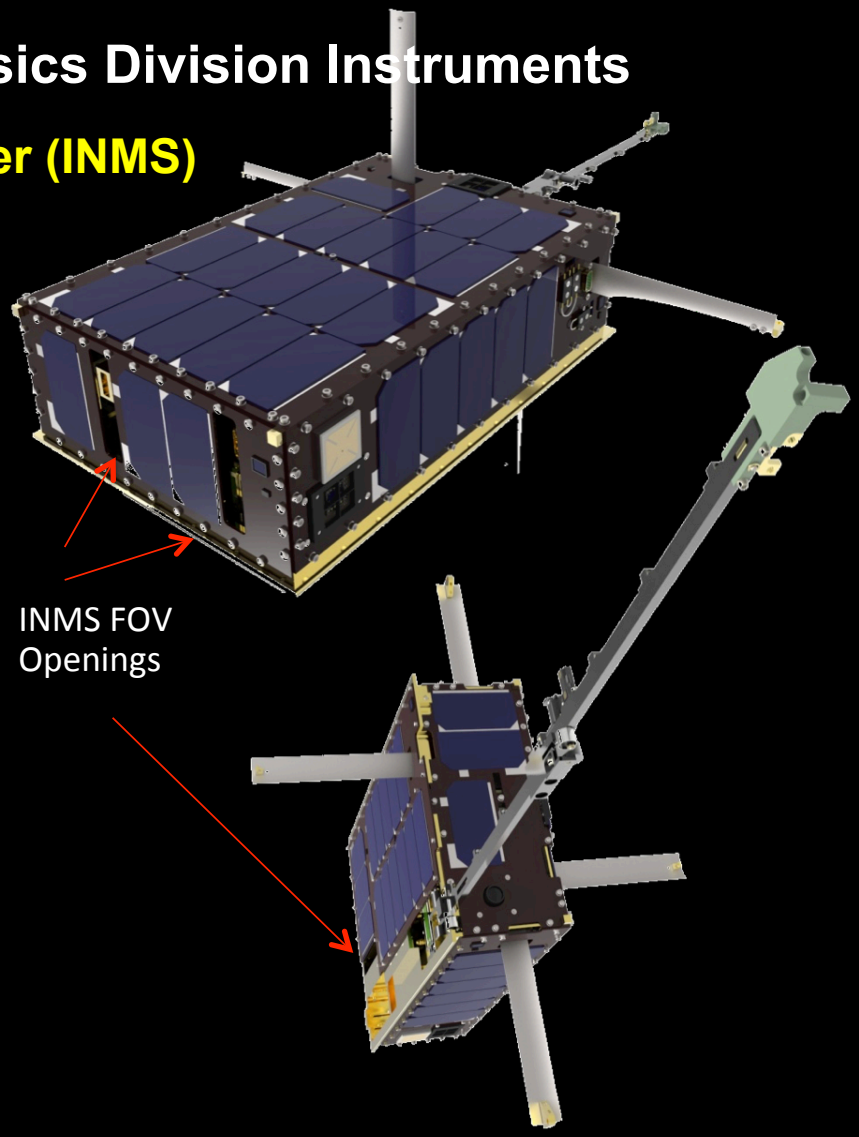
Operate successfully 2 GSFC Heliophysics Division Instruments

Compact Ion and Neutral Mass Spectrometer (INMS)

- Measure ion and neutral composition and densities
- Study of the dynamic ionosphere-thermosphere-mesosphere system and coupling to the steady state background atmospheric conditions

CubeSat Science Magnetometer

- Miniaturized fluxgate with better than 0.1nT resolution at 3.5 Hz
- Boom (50 cm) and body mounted magnetometers
- Measurement algorithms null spacecraft-generated disturbance fields

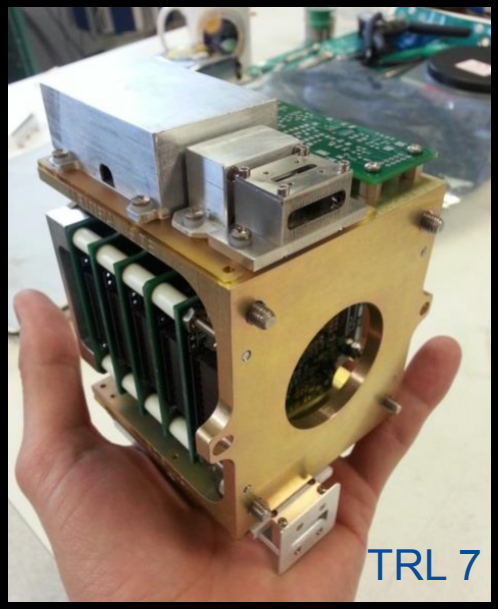


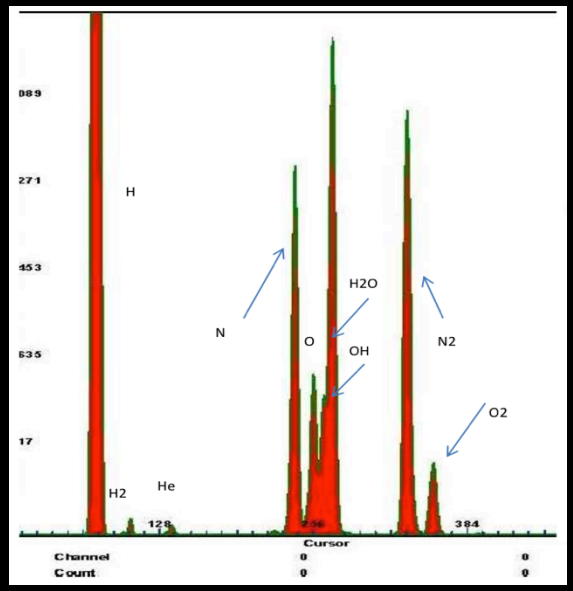
Dellingr:
GSFC-Developed Flagship Quality Instruments

Advanced gated time of flight mass spectrometer (INMS)

This ion/neutral mass spectrometer uses pre-acceleration and Gated Time of Flight analysis to differentiate species and is designed specifically to resolve neutral and ionized H, He, and O.

- Required measurements on 3 of 4 Heliophysics Decadal Survey strategic missions





- 0.56 kg, 8cm x 12 cm, max power 1.6W (at full filament 100mA)
- Mass resolution M/dM ~10, dynamic range
- 1-40 amu, max counting rate: 1 Mcps

Ref. Paschalidis/GSFC

Dellingr:
GSFC-Developed Flagship Quality Instruments

Operate successfully 2 GSFC Heliophysics Division [illegible]s

Compact Ion and Neutral Mass Spectrometer (INMS)

- Measure ion and neutral composition and densities
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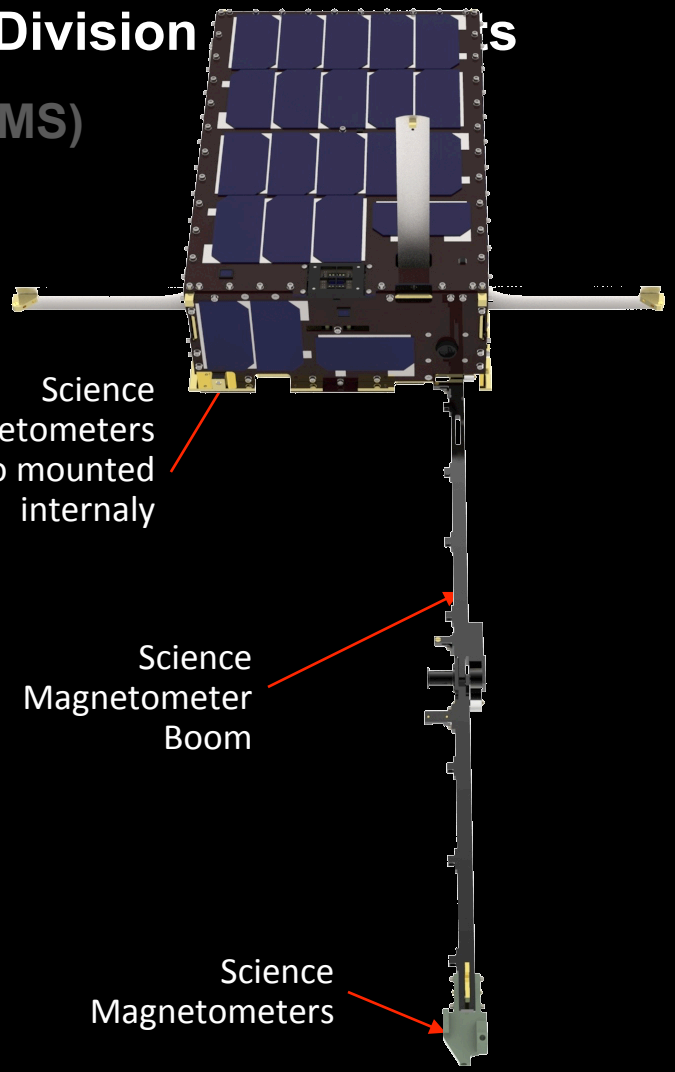
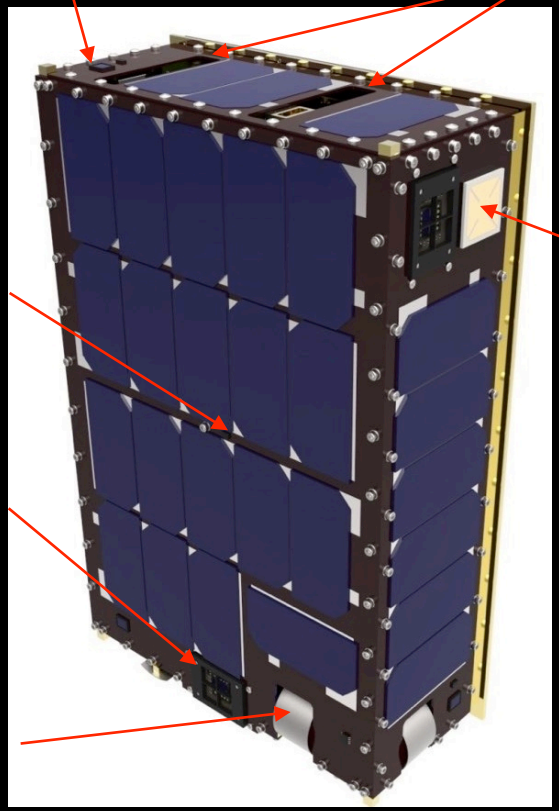
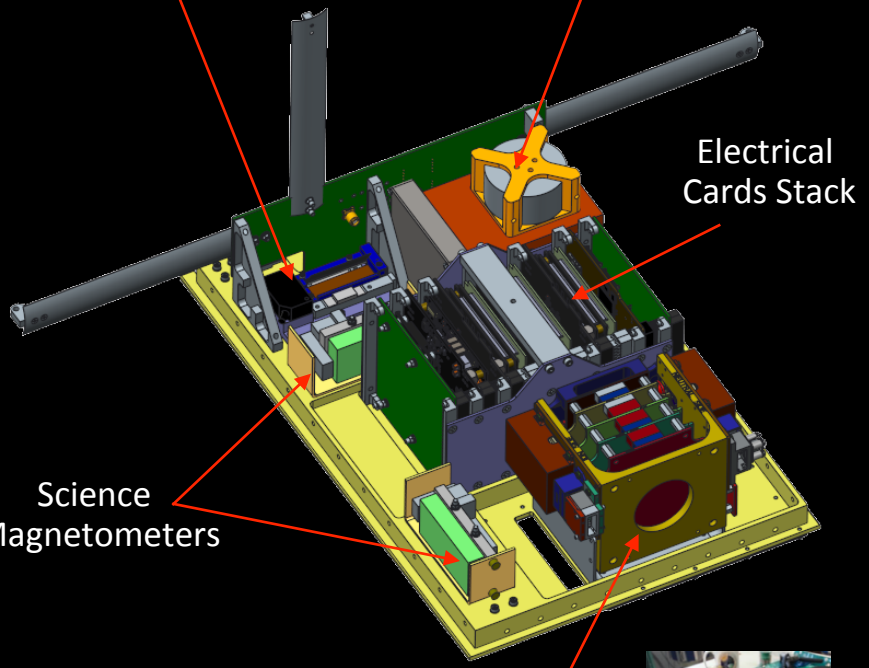
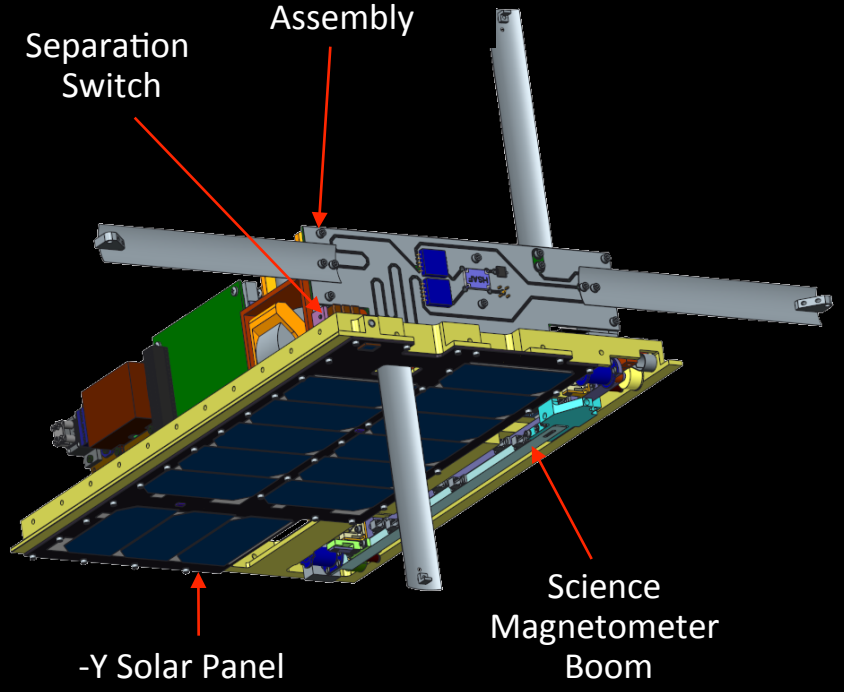


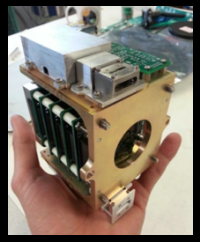
Dellingr:
External Components, Stowed



Dellingr:
Internal Systems



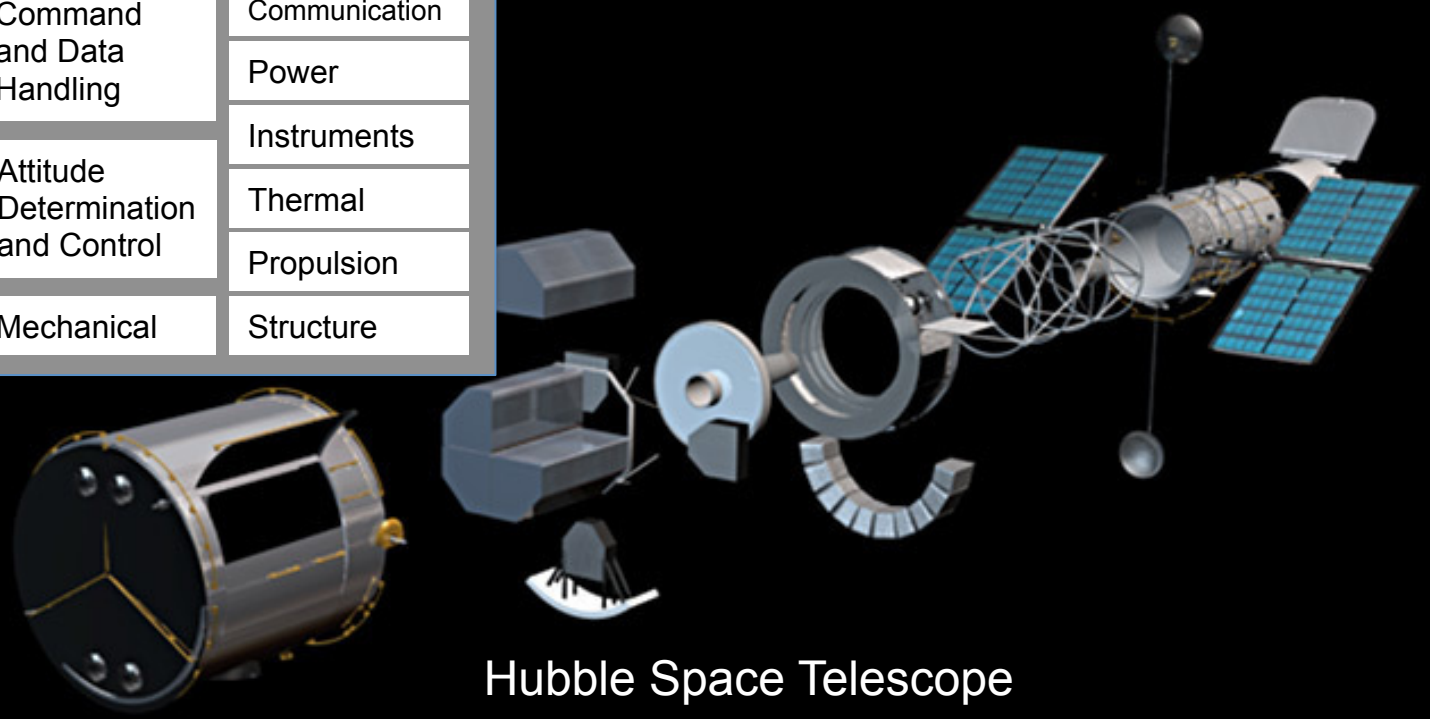




Ion and Neutral Mass (INMS) Spectrometer
Paschalidis/GSFC

Dellingr Take-Homes:
Spacecraft Subsystems

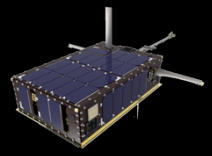
Command and Data Handling	Communication
	Power
	Instruments
Attitude Determination and Control	Thermal
	Propulsion
Mechanical	Structure



Hubble Space Telescope

Dellingr Take-Homes:
Spacecraft Subsystems

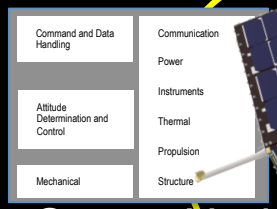
Command and Data Handling	Communication
	Power
	Instruments
Attitude Determination and Control	Thermal
	Propulsion
Mechanical	Structure



Dellingr

It’s still a spacecraft.

Dellingr Take-Homes:
Robustness Requires an Integrated System Approach

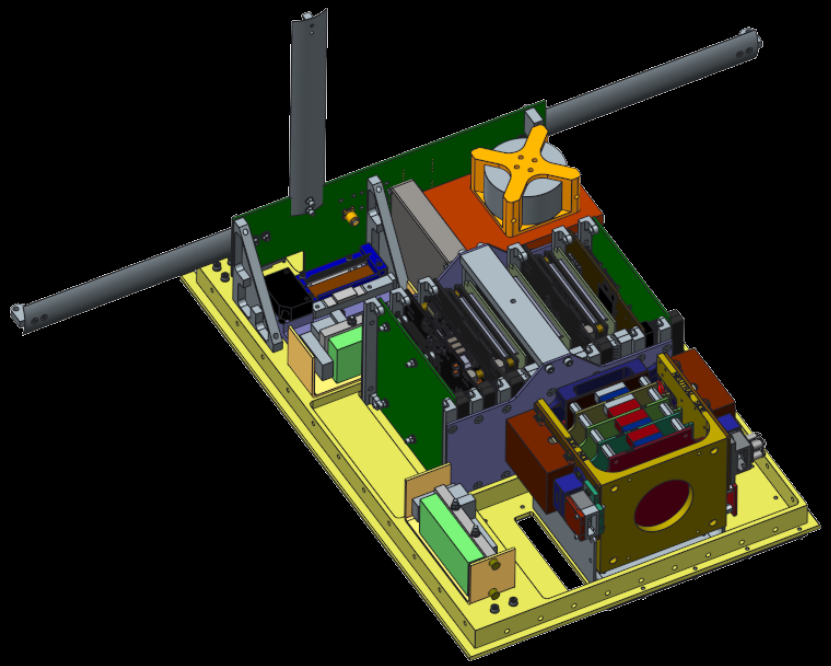


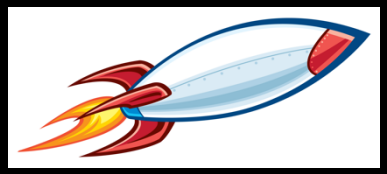
Space Node

Ground Nodes

End Users

Dellingr Take Homes:
Parts



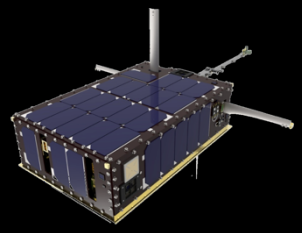


"Fill in the Blank" Space Parts (est. 2015)
Best parts in the galaxy!

- "Oh, by the way, we changed xxx"
- "Parts had fingerprints all over them."
- "Sorry. We threw the bad part away."

Tread carefully…

Dellingr Take Homes:
Building Small in a Large Build Organization



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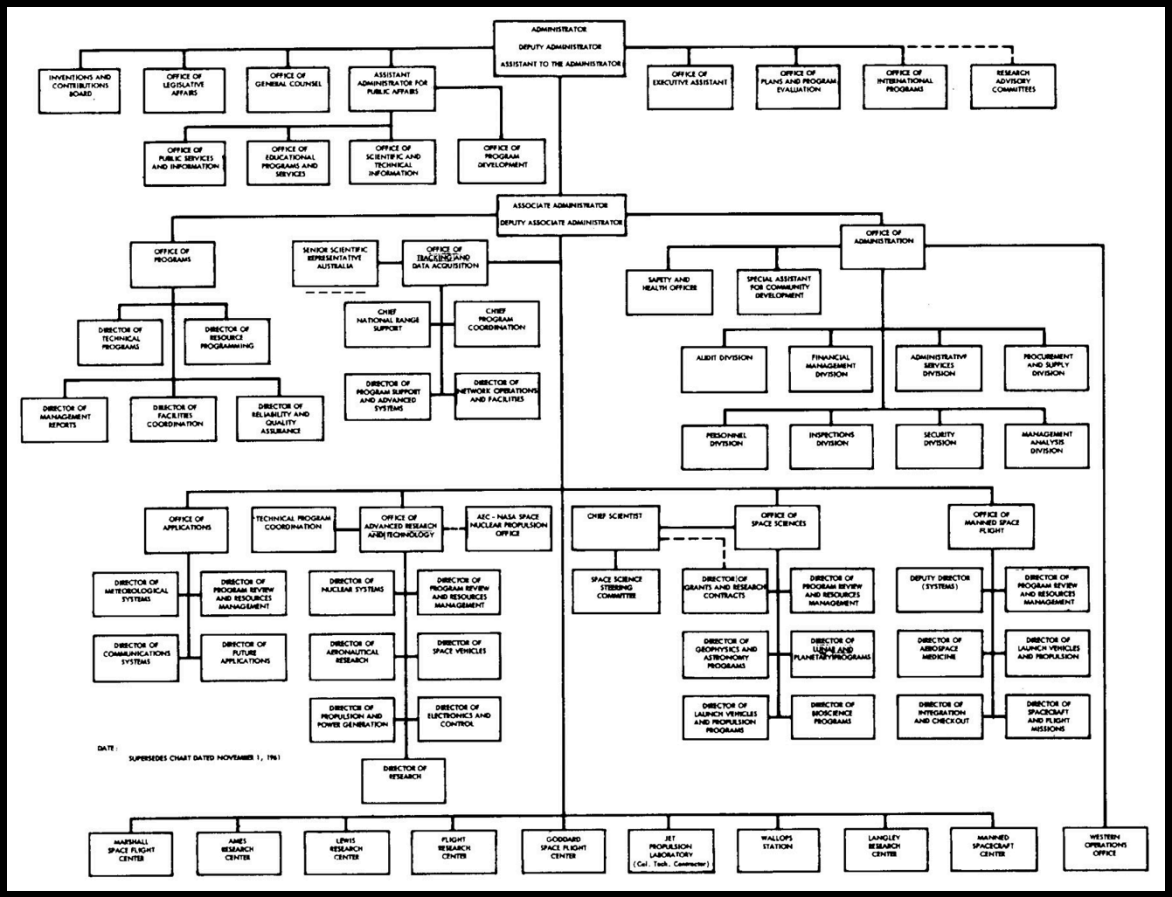
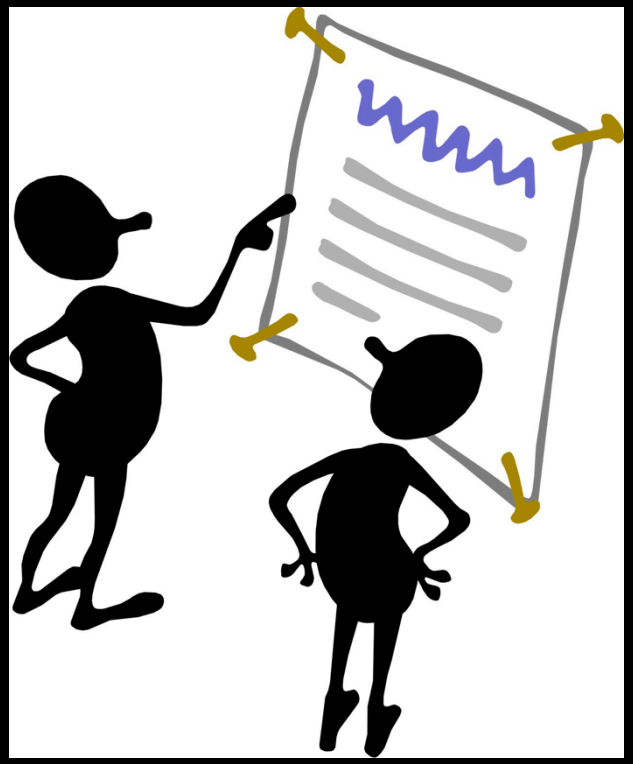


The right organization structure for the right job…

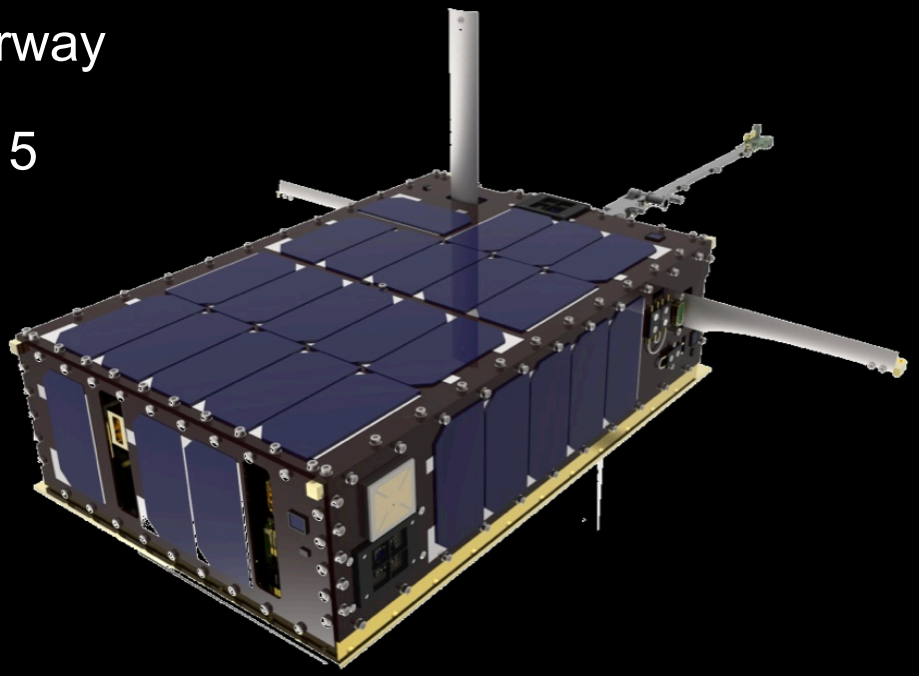
Dellingr Take Homes:
Collaborate and Communicate



Great things can happen when people talk to each other…

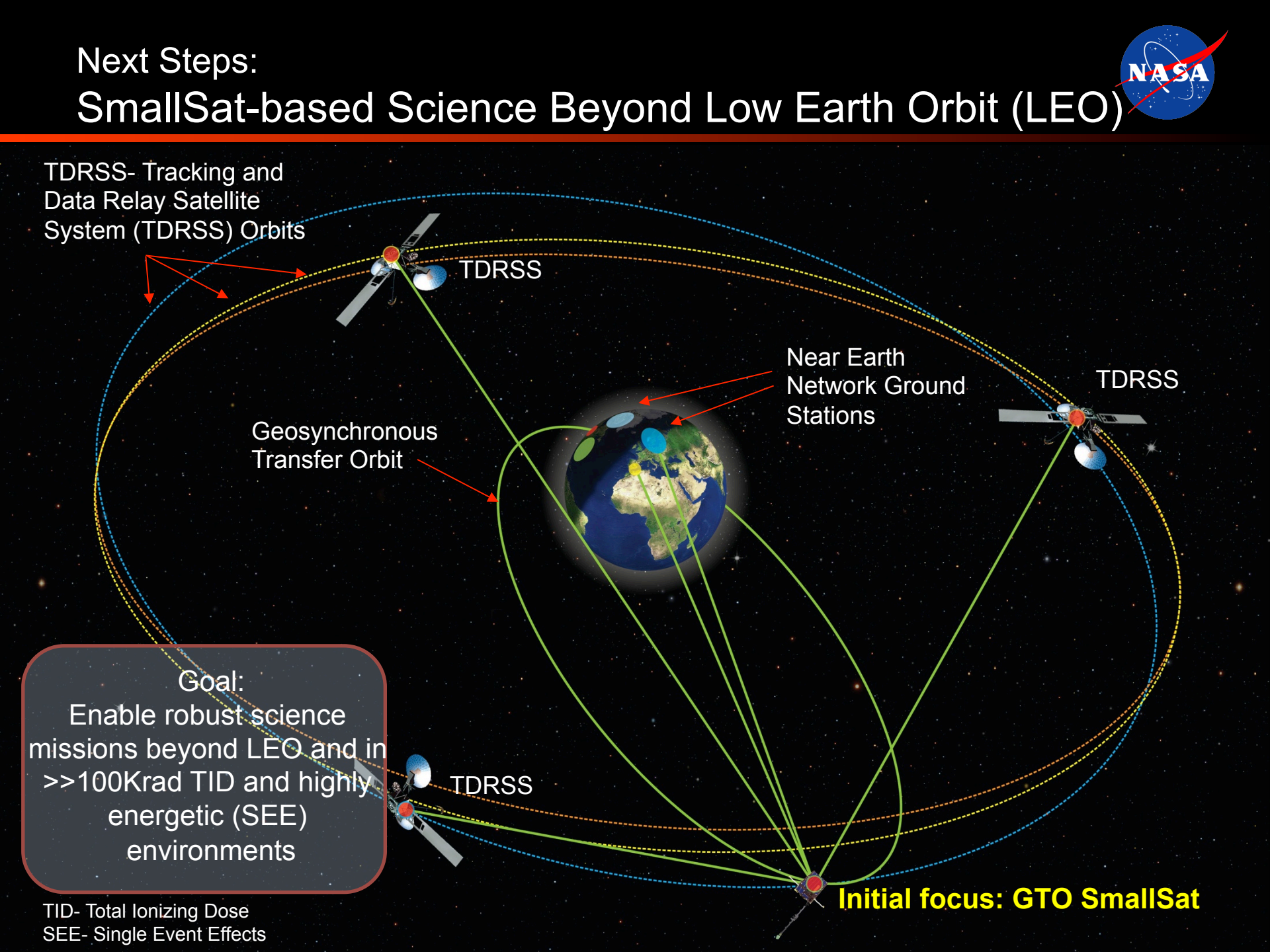
Dellingr:
Status

- Systems integration nearly underway
- Environment test begins late 2015
- Flight readiness Q2 CY2016



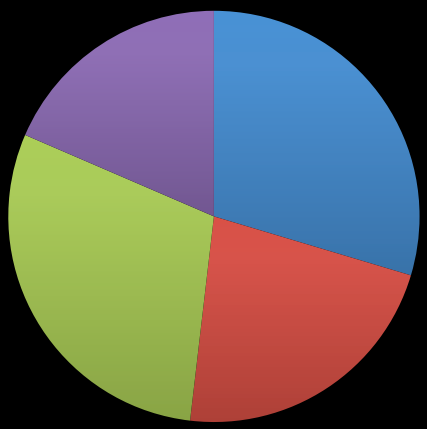
Lessons learned during development are pathfinders to next steps:
beyond low earth orbit GSFC SmallSat science

Next Steps:
SmallSat-based Science Beyond Low Earth Orbit (LEO)

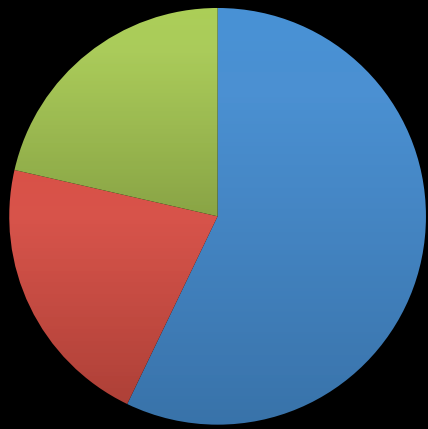


TID- Total Ionizing Dose
SEE- Single Event Effects

Next Steps:
Reliability Not Sufficient for "NASA Class" Science



University Mission Status for Spacecraft Reaching Orbit - Second Mission – (2000-2014).



Industry Mission Status for Spacecraft Reaching Orbit - Second Mission - (2000-2014).

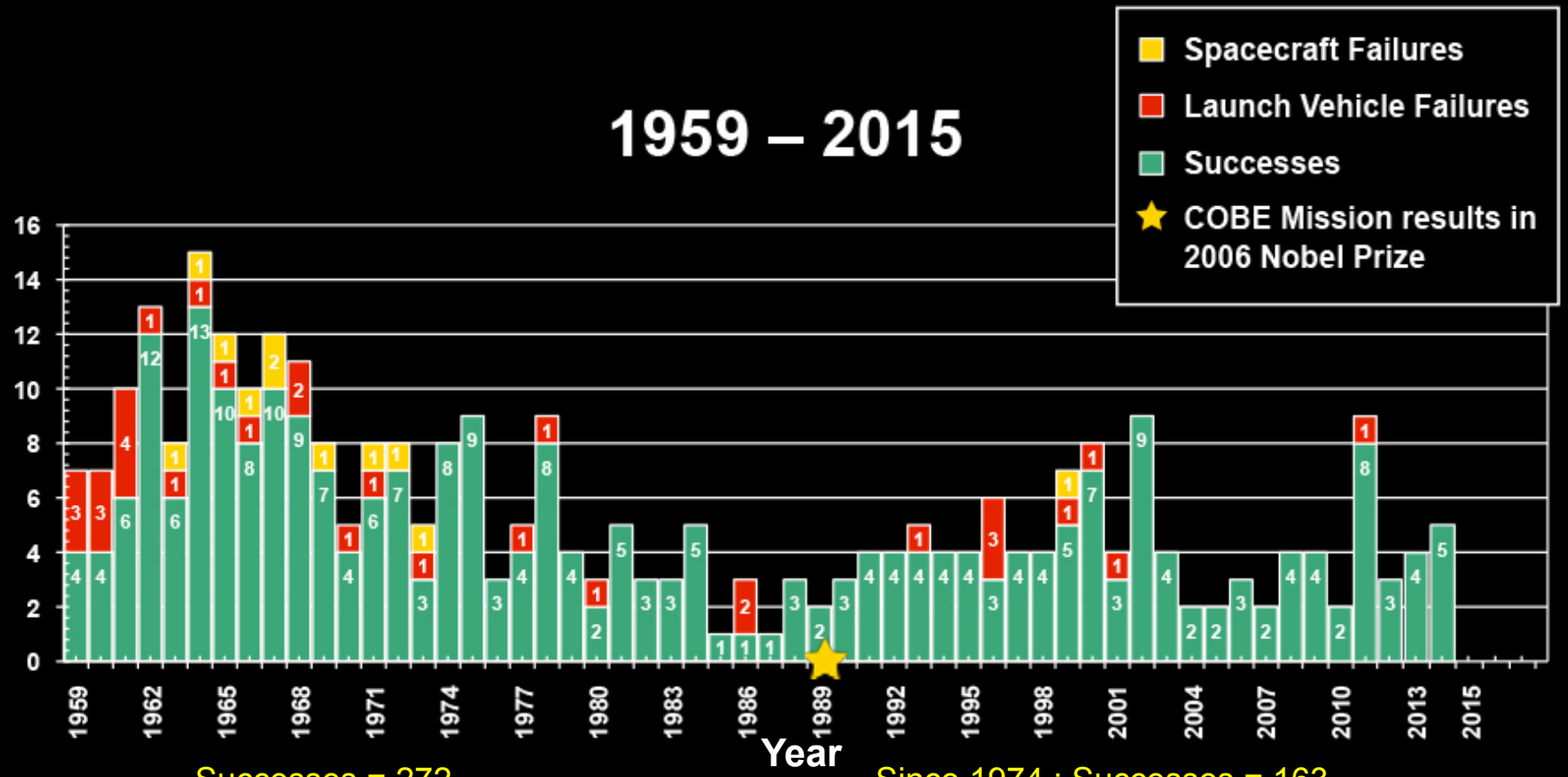
Ref. M. Swartwout

Next Steps:

Beyond Low Earth Orbit

Goddard's mission success performance informs our success posture

- And is inconsistent with historical CubeSat mission success



Successes = 272
Launch Vehicle Failures = 32
Spacecraft Failures = 12

Since 1974 : Successes = 163
Launch Vehicle Failures = 14
Spacecraft Failures = 1

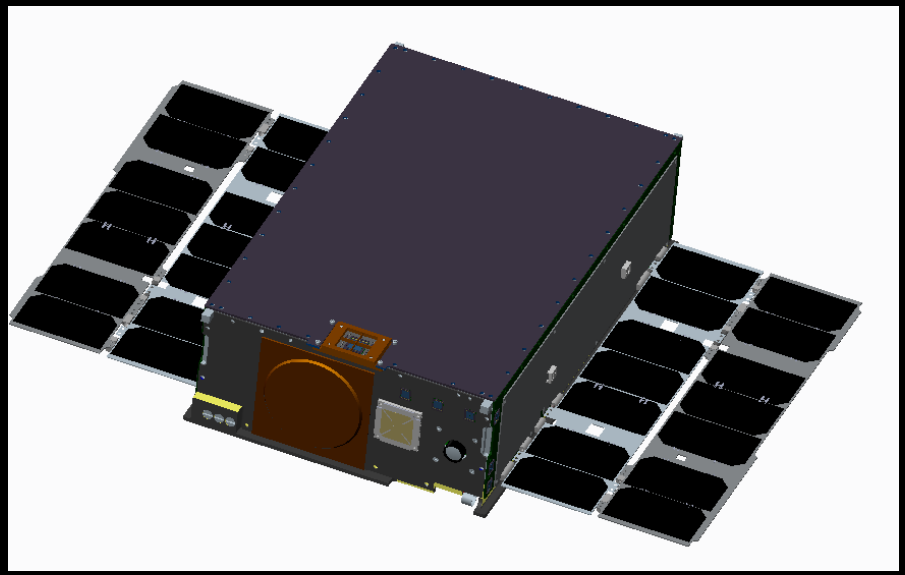
Next Steps:
Beyond LEO Capabilities

Goal- Enable Robust SmallSat-based Science Missions Beyond LEO in Challenging Environments… *Without Driving Costs*

Goddard Modular SmallSat Architecture- Facilitate cost and schedule efficiencies via modularity, flexibility, extensibility

Approach: **Fly the Instrument**

- Minimize spacecraft system impact
- Build systems when necessary
- Buy systems when appropriate
- Engage vendors to meet mission requirements

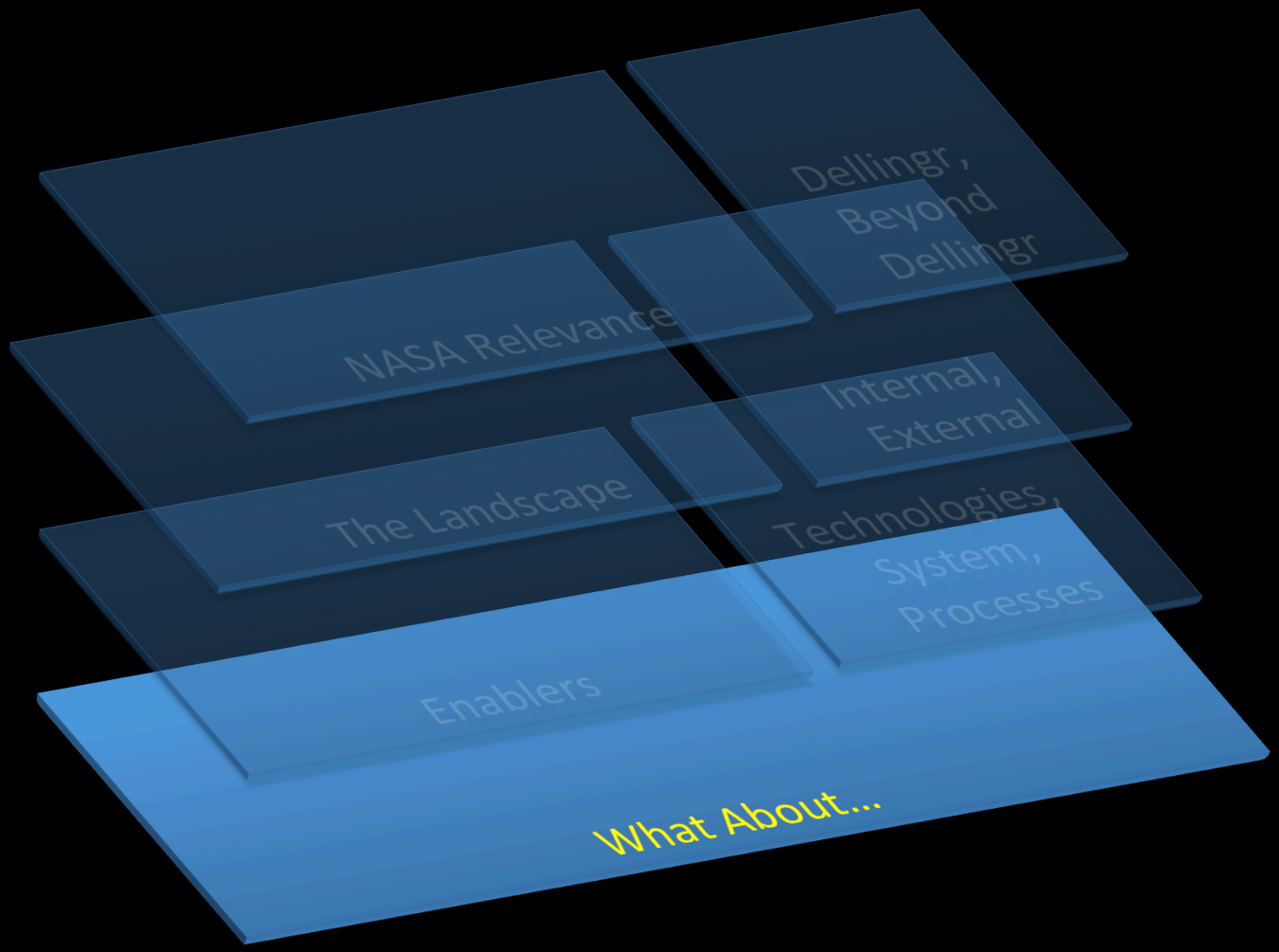


Select Major Foci

- Systems Engineering
- Radiation Mitigation
- Modular Systems
- Autonomy

Next Steps:
Beyond LEO Capabilities

GSFC is postured for SmallSat science beyond LEO

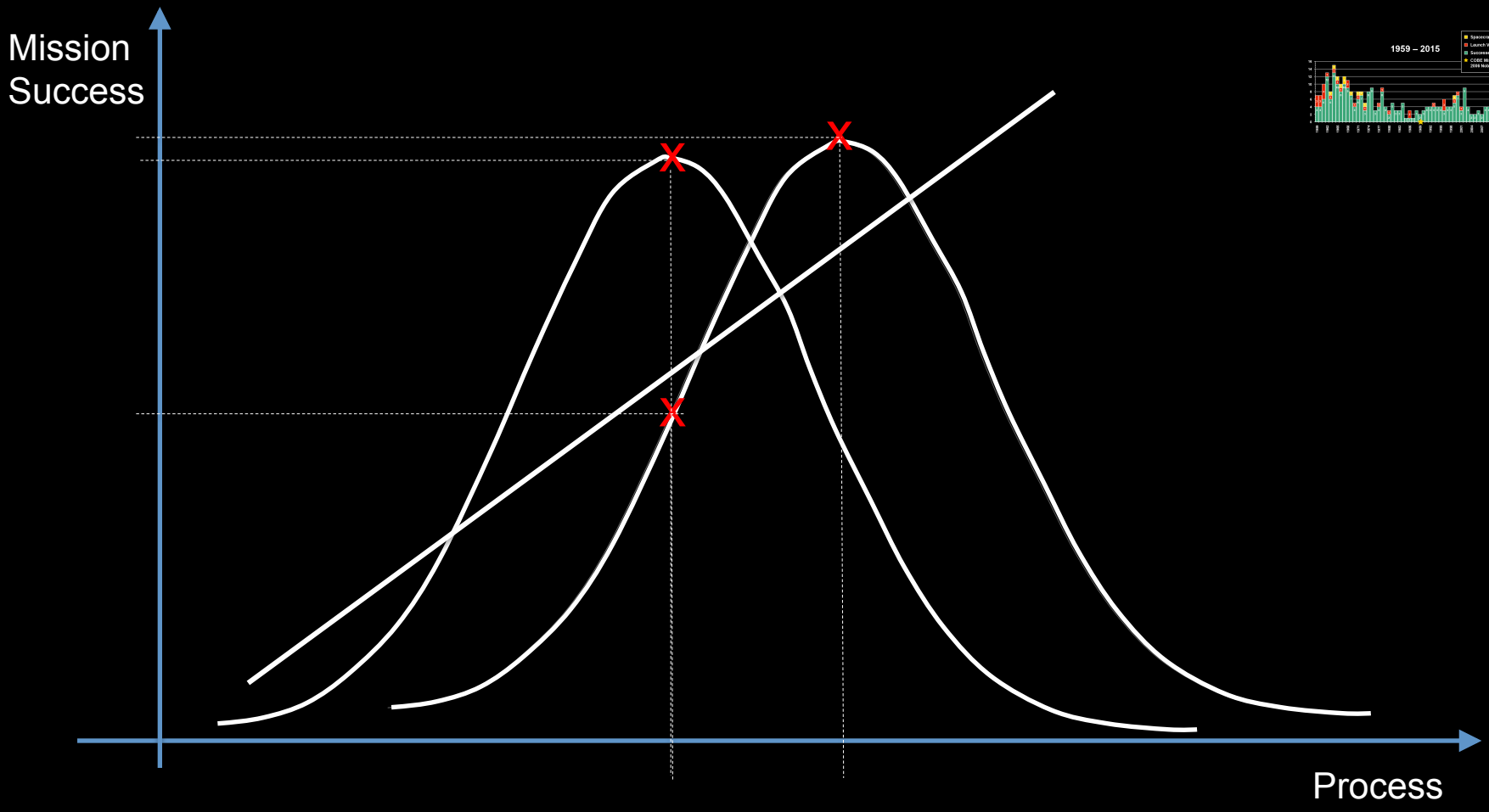

Dellingr, Beyond Dellingr
NASA Relevance
Internal, External
The Landscape
Technologies, System, Processes
Enablers
What About…

What About…

This is not just about CubeSats.

What About…

"How"? Innovation Required.



Process = f(…, cost, schedule)

What About…

Is the strength of a “heritage” organization also its weakness?

If so, what?

What About…

The “Phyllis Postulate”?

What About…

Can we risk “non-linear” thought?

What About…

How specifically do we apply this beyond SmallSats?

In Closing…

This is not your mother's (or father's) space.

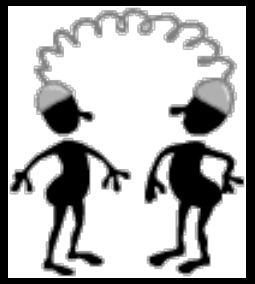
CubeSats-SmallSats are enabling transformation.

But "New Space" ideas transcend these platforms.

It's not just about "what". "How" is just as important.

Communicate and collaborate.

"Think different." Today's thought may be inadequate for tomorrow's challenges.

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