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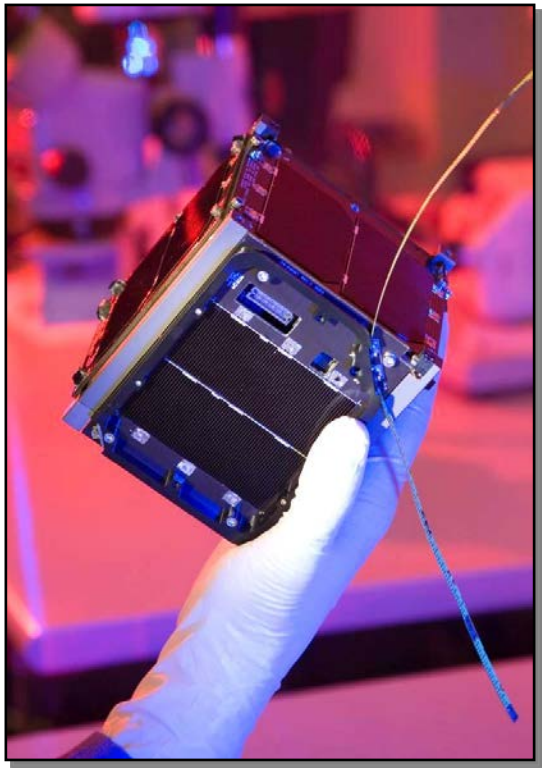
Is Innovation Enough to Help CubeSats Survive Their Evolution?



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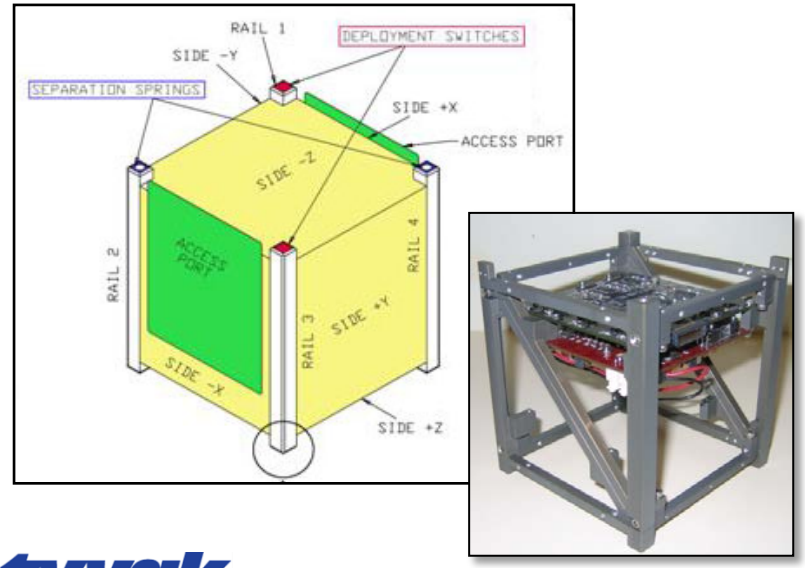
23 August 2011

The CubeSat Standard

Background

- Started in 1999 by Stanford University and Cal Poly Teams
- Driven by Need to Facilitate Access to Space
  - Rapid development time (1 - 2 years: student's "career")
  - Very low-cost
  - Launch vehicle flexibility



CubeSat Design Specification

- Standard Based On:
  - Simple access to Space environment
  - Size of common COTS components
    - Solar cells, batteries, transceivers, etc.
  - Self-imposed safety standards
- Defines Shape, Size, Mass and Interfaces
- Specifies Materials and Tolerances
- Outlines Initial On-Orbit Operations
  - Restrained Deployables
  - Initial Communication
- Simple Document

CubeSats Provide "Containerization" and Standard Interfaces

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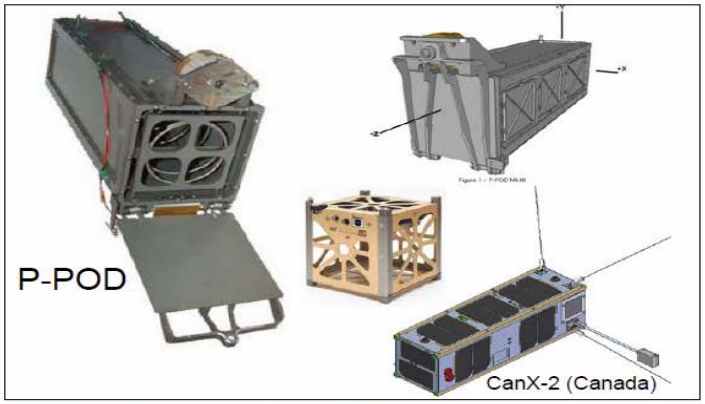

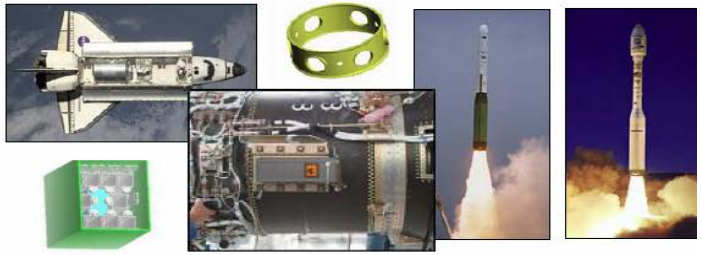

A Revolution in World-Wide Transport ⟷ *A Revolution in Space Transport*

- **P-POD Design Objectives:**
  - Safe/reliable deployment
  - Compatibility with many launch vehicles
  - Simplicity
  - Protect launch vehicle and primary payload
- **Accommodates 3 Single CubeSats**
- **Rectangular Tubular Enclosure**
  - Fully encloses CubeSats ("Do Not Risk Primary")
  - Access panels
- **Simple Spring Assisted Ejection**
- **Commonly Used Deployment Initiator**
- **Redundant Switches Verify Deployment**

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CubeSat Flown to Date and Launch Trends

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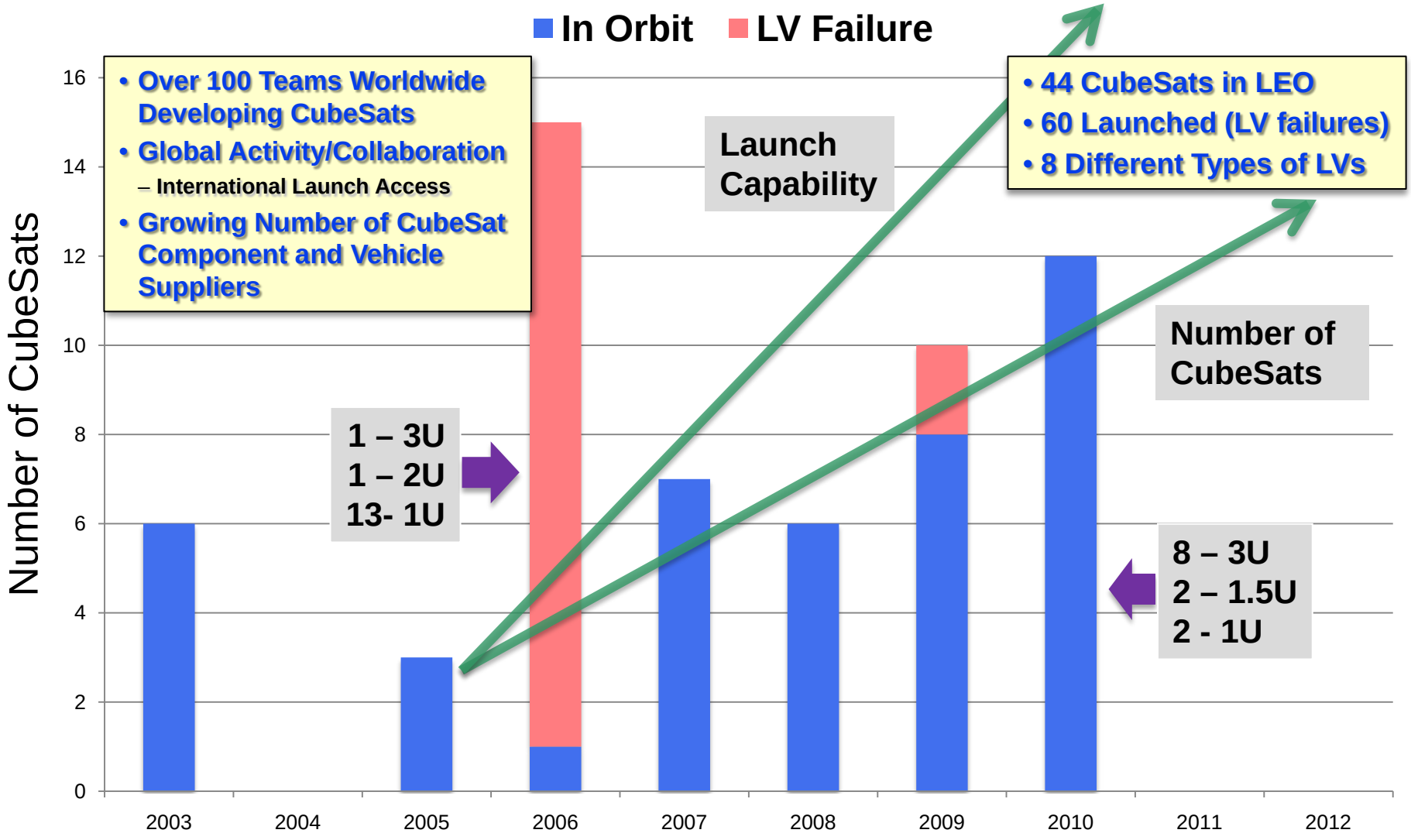

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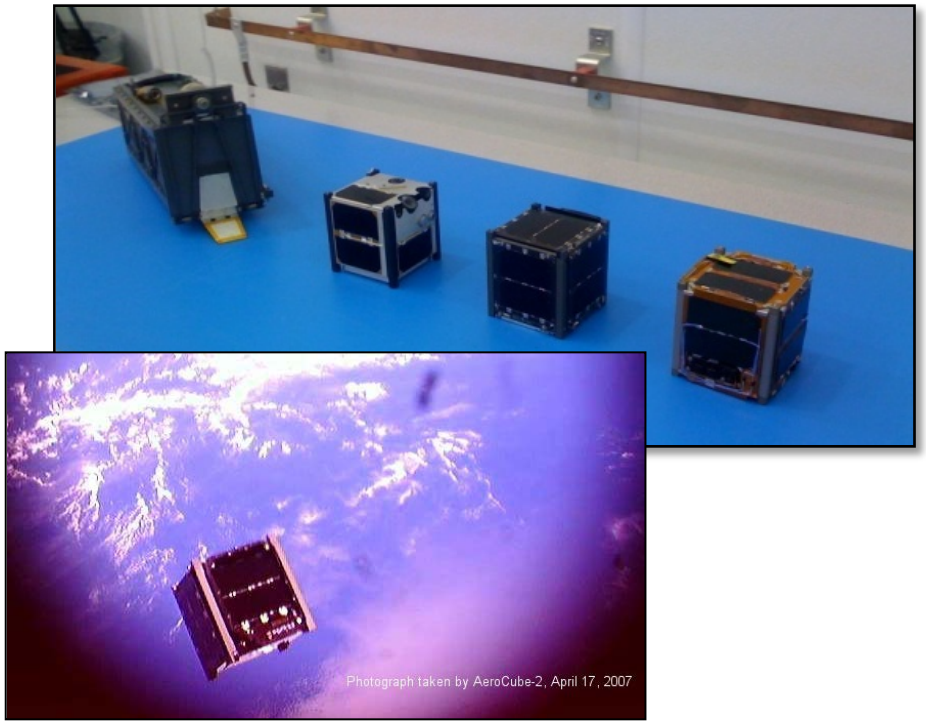
Why Has CubeSat Been a Successful Standard?

- **Small and Very Low-Cost**
  - Large Developer Community = New Developers + Commodity Components
- **Hard Standard**
  - Physical constraints
- **Advances in Miniature Electronics**
- **Primary Spacecraft & LV Protection**
- **Maturity Provided by Quick Repetition Minimizes Design, Analysis, and Testing**
- **Decoupling Spacecraft ⇔ Launch Vehicle Manifest**
  - LV manifest without firm spacecraft
- **CubeSat Standard is Independent of Launch Vehicle**
  - "Off-the-shelf" CubeSat
  - Interchange spacecraft between LV's
- **Grass Roots Effort Lead by Universities**
  - Industry & Government Joined Later
- **Creativity and Imagination**
  - Can Do Attitude
- **Higher Acceptance of Risk**



Significant Reduction in the Cost of Spacecraft and Launch Is Driving Innovation

- **High Launch Costs for Satellite Missions**
  - **Even the cheapest dedicated launches approaching $10Ms**
- **Forces Significant Pressure to be "Risk Adverse"**
- **Results in Path Towards Larger, Higher-Reliability and More Expensive Satellites**

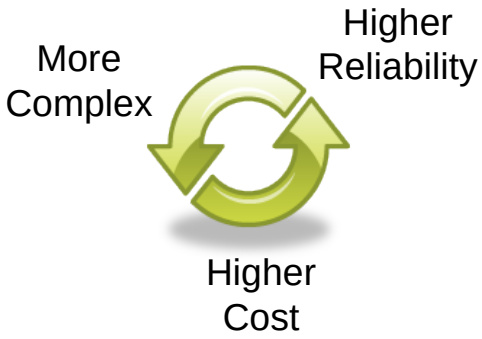
- **CubeSats Bring a New Paradigm**
  - **Ultra low-cost space access to space**
  - **CubeSat standard, launch brokering service, and frequent launch opportunities**
- **Permits Higher Risk, with Low Cost of Failure**
- **Leads to New Approach to Satellite Development**
  - **Inspires creative, 'out-of-box' thinking**
  - **Smaller systems facilitate rapid development cycles**

Growing CubeSat Need for Mission Assurance & More Capability

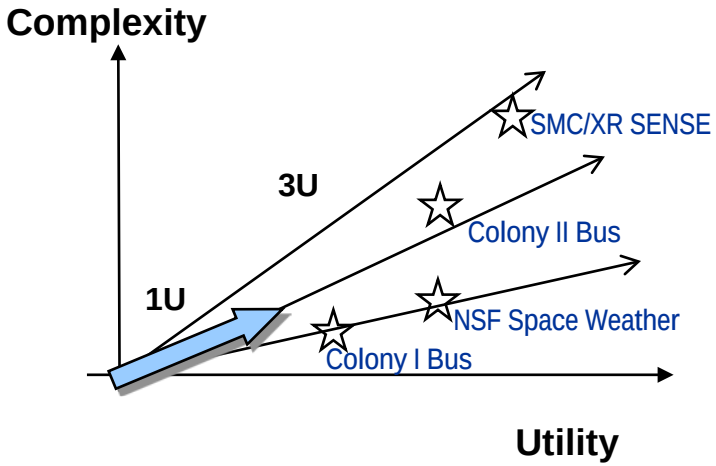
- Need to Balance with Keeping CubeSats Simple and Low Cost

- **As a Natural Progression of Technology, Things Become Increasingly Complex and More Diversified**

- **In The Beginning…**
  - **Predominantly 1U CubeSats**
  - **Simple payloads**
  - **Mission life of weeks to months**
  - **Simple attitude control**
  - **Simple communications leveraging amateur equipment**
  - **'Disposable'**



- **… Progressing To …**
  - **Numerous 3U CubeSats**
  - **Multiple payloads on a single CubeSat**
  - **Mission life of greater than a year**
  - **Precision 3 axis attitude control**
  - **Higher frequencies, larger bandwidth, and increasing COMSEC requirements**
  - **'Higher Reliability'**



Representative *Space-Focused* Missions and Technologies

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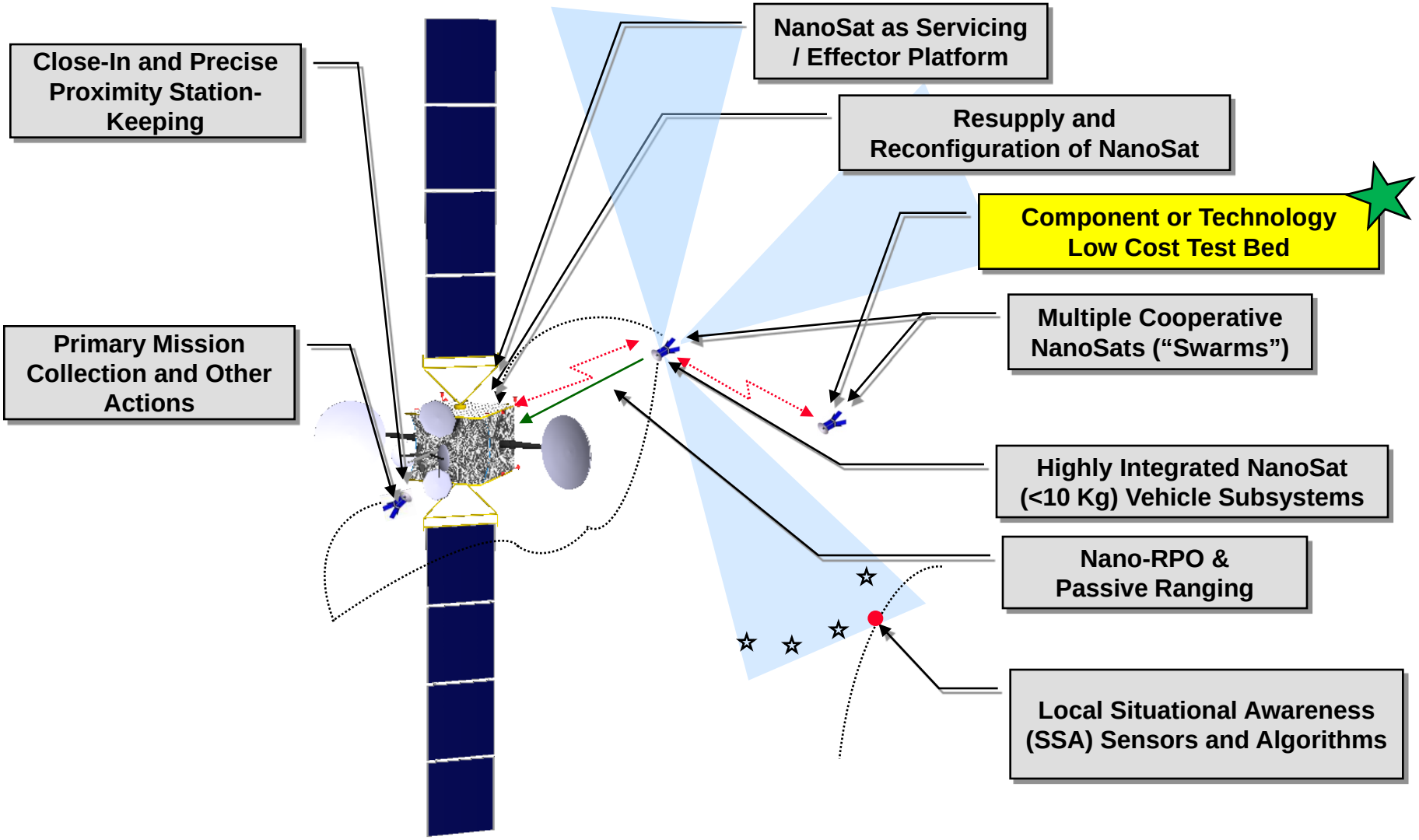

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Representative *Ground-Focused* Missions and Technologies

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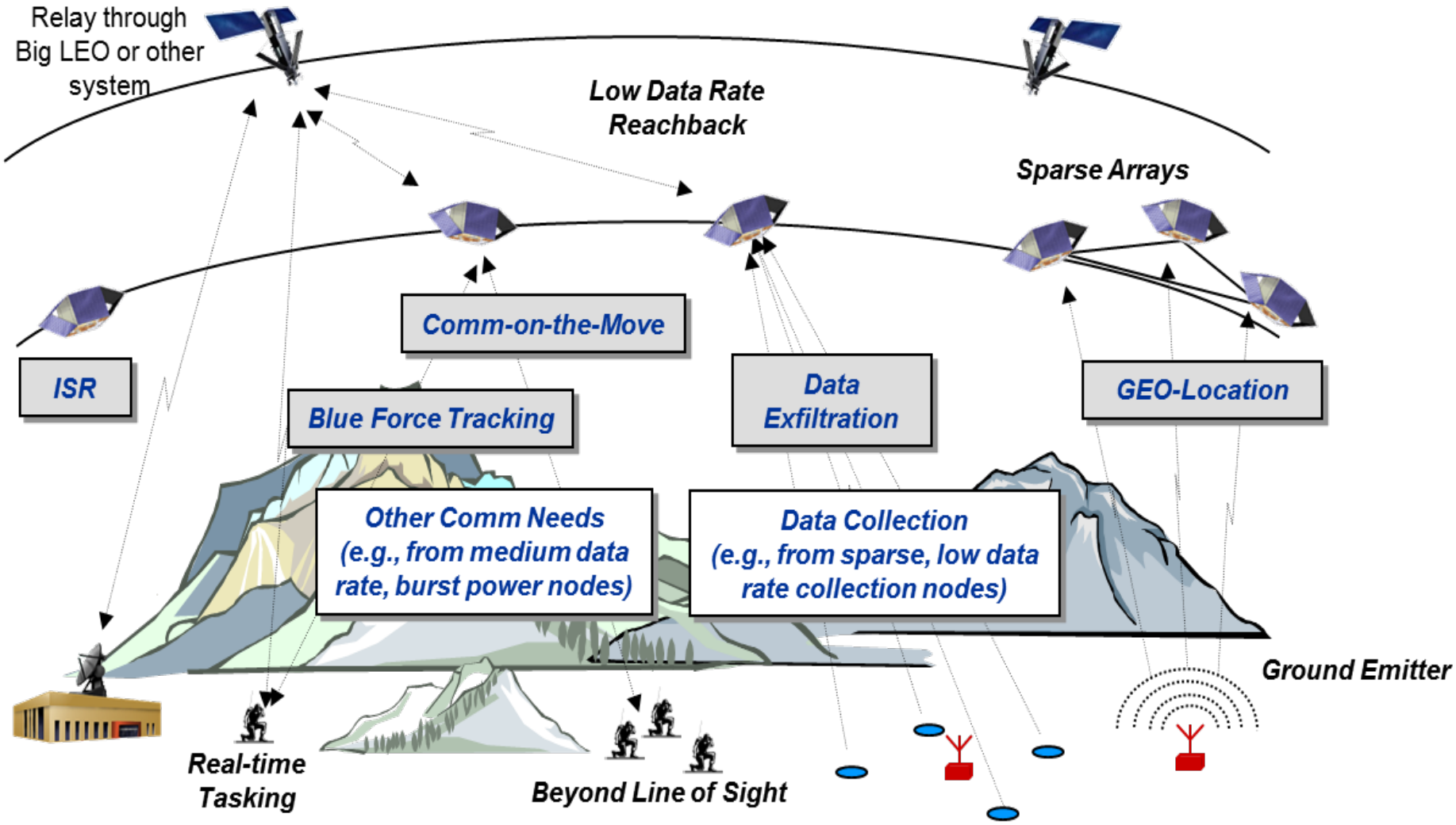

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How Do We Measure the Utility of NanoSats?

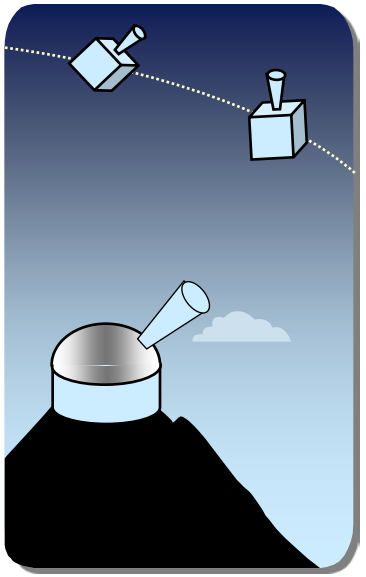
- How Do We Exploit the Strengths of NanoSats?

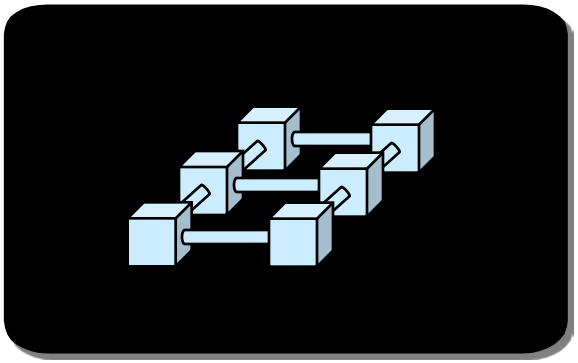
- **Utility is Measured the Same Way We Do For Larger Satellites**
  - **Availability**
  - **Coverage**
  - **Resolution**
  - **Etc.**

- **Key Attributes of NanoSats**
  - **Less expensive to build and launch**
  - **Deploy in quantity**
  - **Small size**

Operate in Proximity
- **Resolution**
- **Availability**

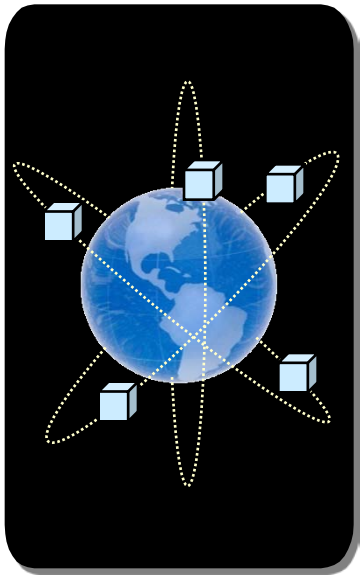
"A 5 inch television looks like a big screen when you are sitting 15 inches away"





Modular, Reconfigurable Vehicle
- **Adaptability**
- **Flexibility**

"Lego-Sats"



Deploy Constellations of Vehicles
- **Coverage**
- **Availability**

"Timely coarse data can sometimes be more important than high-fidelity, dated data"

Miniature Deployable High Gain Antenna

- Addresses Key Issue with Small Spacecraft

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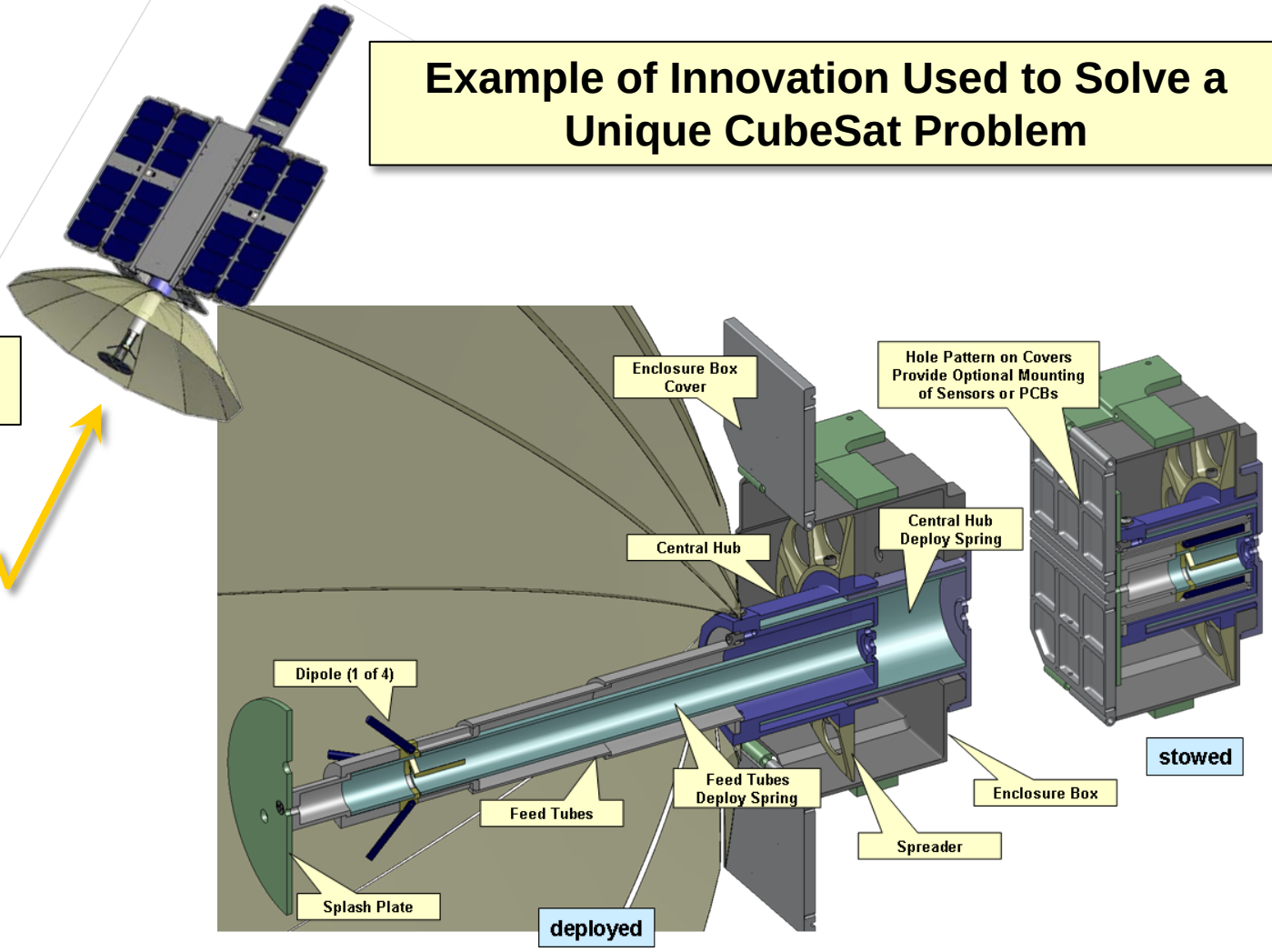
Example of Innovation Used to Solve a Unique CubeSat Problem

Enables Communications Directly to the Warfighter



Developed Under Contract with the NRO

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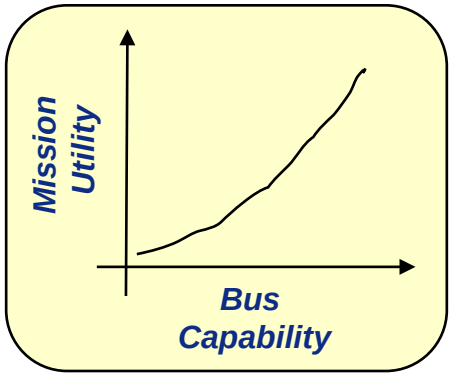
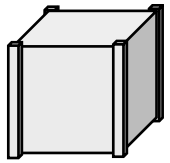
Capabilities Needs are Growing and Inter-Related

- Additional Capability Needed to Enable Operationally and Scientifically Relevant Missions

Evolution of Nano-Satellites-
Capability Growth is Inter-Related





Challenge: How to Package More Capability into CubeSat Envelope

Values are Notional

New Fabrication and Assembly Approach Needed to Support Highly Integrated Systems

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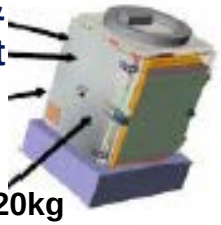
Current Approach to Small Satellites

Space-Rated Boxes / Components
(smallest mass, power, and size)

Collection of Subsystems (Integration of boxes and systems)

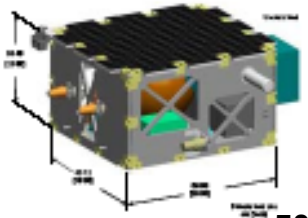
Examples:

AFRL Plug & Play Sat



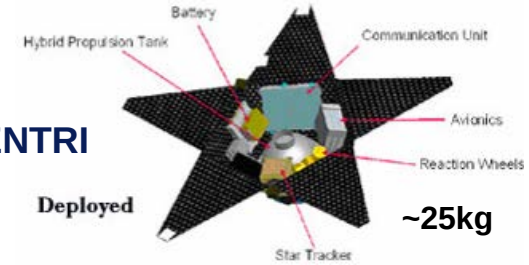
~120kg

LM ANGELS Bus



~50kg

SpaceDev SENTRI



~25kg

Needed Approach to Get To *Ultra* Low Power & Size

Space and Commercial Components
(smallest mass, power, and volume)

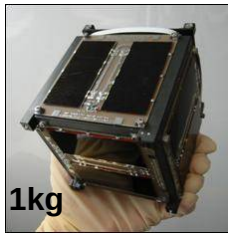
Highly Integrated System (Integration of lower level components)

Examples:

Boeing Colony II Bus

4 kg

Cal Poly CP2 CubeSat



1kg

SSTL Snap

6-12kg

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The Tyvak™ *Intrepid* Pico-Class CubeSat Suite

- Integrated High Performance System Bundle in Smallest Volume

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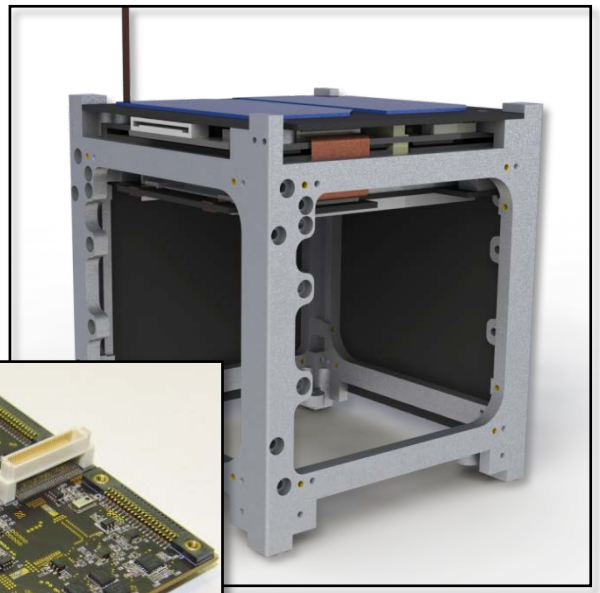
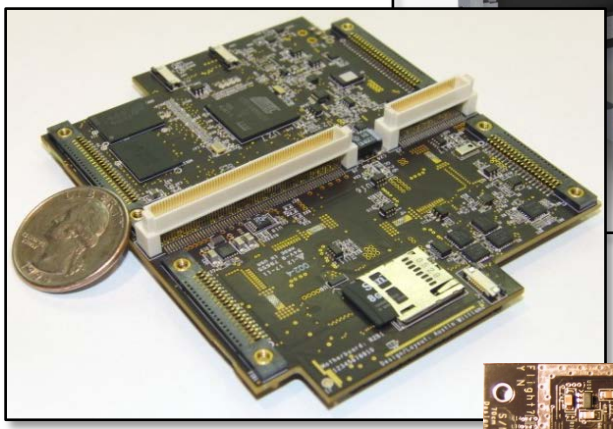
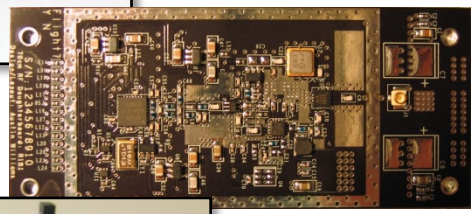
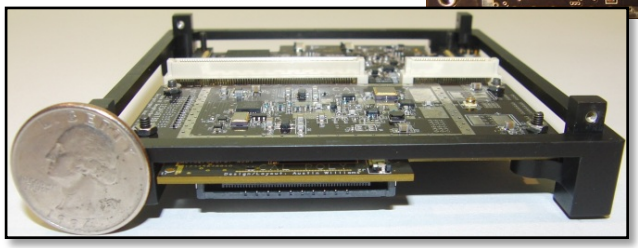
- ***Intrepid* System Board**
  - 400Mhz ARM Processor; >512MB of Storage, 64MB RAM at <0.3 Watts
  - Embedded Linux
  - Integrated Power Regulation System and Sensor Suite
- **Low Profile UHF Radio Daughterboard**
  - 1W RF Out, Up to 250 kbps
- **Multi-Functional Side Panels**
  - 28% Solar Cells, Sensors, Torque Coils
- **Software Tools**
  - Open Source OS and Drivers
  - Simple Development Platform Available
- **Represent Minimal Bus Volume**
  - Core Avionics, EPS, Communication, and Payload Interface in a 9 x 9 x 3 cm Package









Example of Innovation Used to Solve a Key CubeSat Problem

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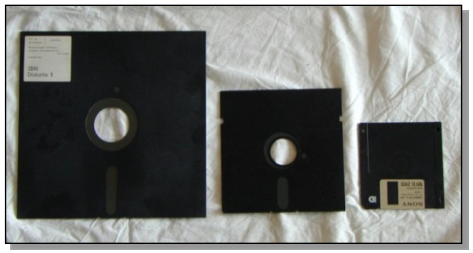
Are CubeSats a Disruptive Technology?

Sustaining technologies **improve performance of established products, along dimensions of performance that mainstream customers in major markets have historically valued**

- ***Breakthrough*** **sustaining technologies substantially improve product performance**



Ref: http://www.tonh.net/museum/3flopsizes.jpg

Ref: http://www.sharp.com

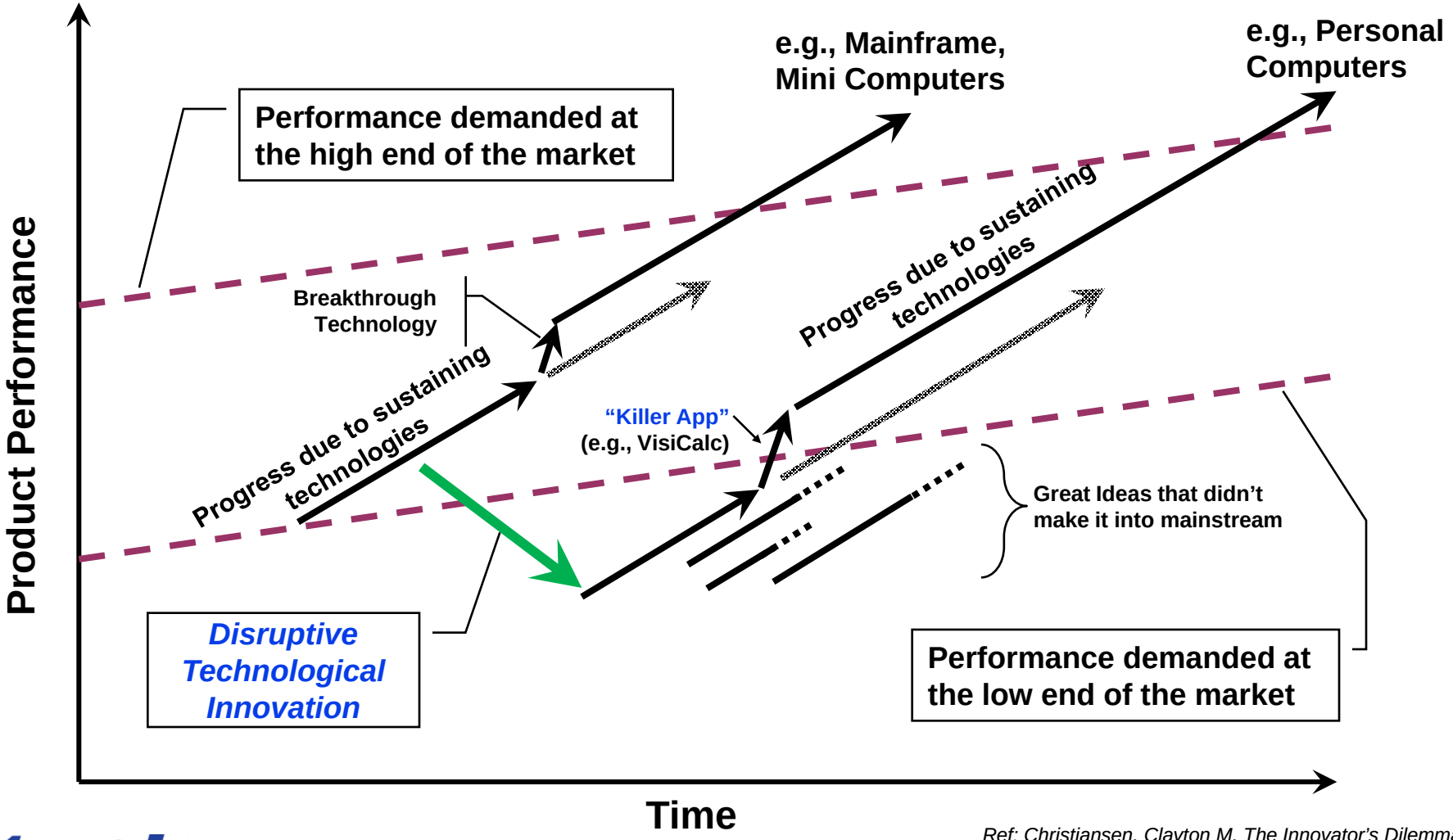
Disruptive technologies **bring to a market a very different value proposition that had not been available previously**

- **Generally, disruptive technologies underperform established products in mainstream markets**
- **But they have other features that a few fringe (and generally new) customers value**
- **Products based on disruptive technologies are typically cheaper, simpler, smaller, and frequently more convenient to use**
- **Archetypical Examples:**
  - **Personal Desktop Computers**
  - **Transistors**
  - **HMOs**

Ref: Christensen, Clayton M. *The Innovator's Dilemma*

Disruptive and Sustaining Technologies

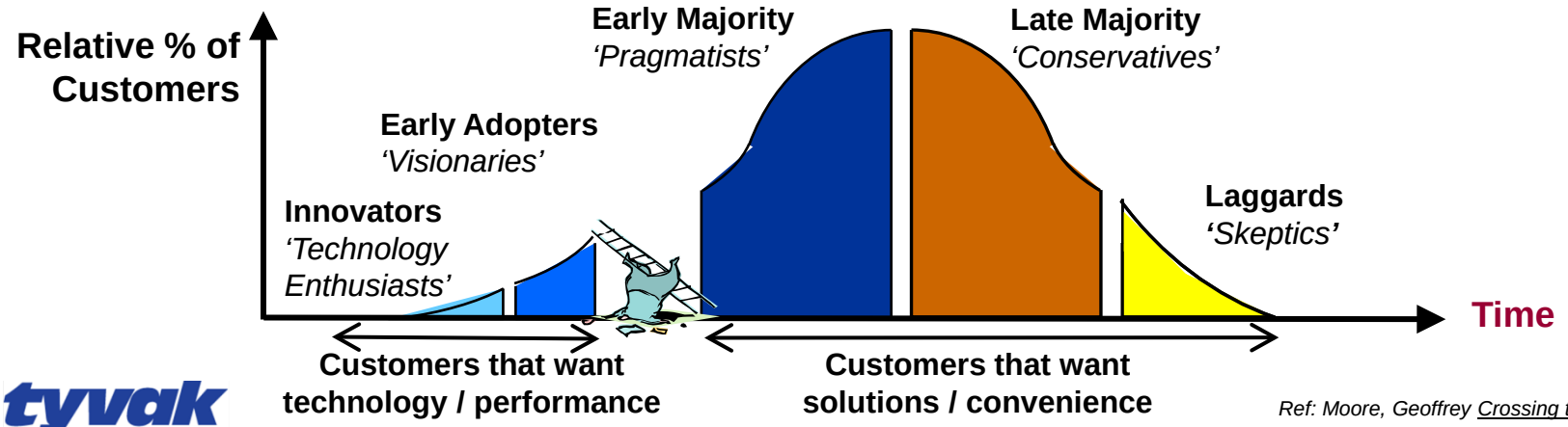
- Disruptive Technology Shifts Market



Ref: Christiansen, Clayton M. The Innovator's Dilemma

Diversification and Maturing of the CubeSat Marketplace

- **CubeSat Principles Were Built Upon Costs Low and Schedules Short to Support University Budgets and Timelines**
- **As With Most New Technologies, It Is Morphed by Other Parties Who See Its Potential (*Visionaries*)**
- **CubeSat Technologies Are Moving To The Point Where People Are Thinking of Real Applications (*Pragmatists*)**
  - **Have we crossed the technology chasm?**
- **Diversification is Evident with Wider Variation of Educational and Industry Applications**
  - **NSF Space Weather, NRO Colony II Bus, SMC/XR SENSE, GAINSTAM Workshop**



Ref: Moore, Geoffrey Crossing the Chasm

Summary

- **CubeSat are Providing Real Value**
  - Engineering "Hand's On" Training
  - Technology Maturation Test Beds
  - Science Data (e.g., Space Weather)
- **Number of CubeSats are Growing**
  - Increasing number of launch opportunities
  - 100's of CubeSat Teams around the World
- **CubeSat Uses are Diversifying**
  - Expanding use by US Government
  - Other mission uses in development

- **Growing Acceptance That CubeSats Can Provide Useful Data**
  - Not just a "University Toy"
- **Government and Industry Sponsored Development Addressing Key Capability Issues**
  - "Power and Aperture", as well as other capability issues being solved
  - Development efforts focused on new set of technologies that will enable useful CubeSat missions
- **Growing Array of Specific Niche Missions**
  - Lots of opportunities…
    - "*like a couple of mosquitos at a nudist colony*!"

With Vision and Leadership Allowing Innovation to Focus on Needed Technologies, CubeSats *Will* Progress to Support Operationally and Scientifically Relevant Missions

Thank You !