CubeSats and the Growth of NanoSpace

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Presentation to the Aerospace & Defense Forum

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Presentation Goal and Outline

- **Goal Of This Presentation Is To Provide:**
  - An introduction to the CubeSat spacecraft and their representative missions
  - Initial awareness of the growing CubeSat market segment
    - To assist in making future market assessments pertinent to your business
- **This Presentation Is Not:**
  - A pitch for a new business opportunity, or specific CubeSat mission
  - Meant to advocate that CubeSats can be used for many of the missions that current spacecraft address

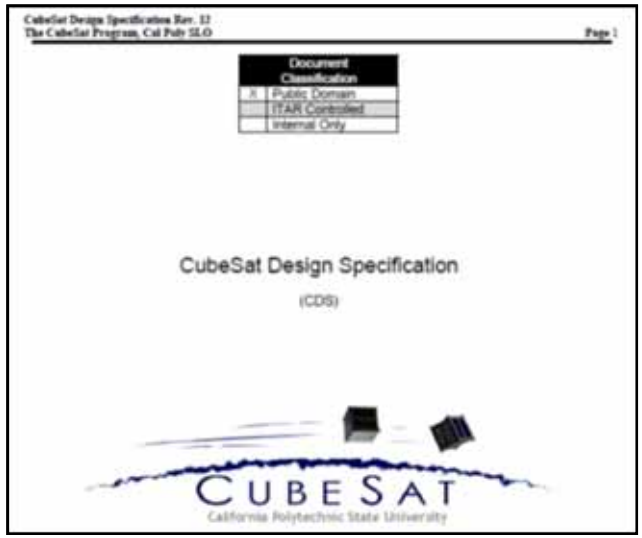
Presentation Outline

- **Background of CubeSats**
  - "What's a NanoSat?"
- **What Makes CubeSats Different and Unique**
- **How Are CubeSats Being Used**
  - Currently, and in the past
  - Ongoing shifts and diversification
- **What Types of Missions Can CubeSats Be Effectively Used**
  - How to leverage their key attributes
  - Examples of some of these missions
- **Some Thoughts on The Future…**

The CubeSat Standard

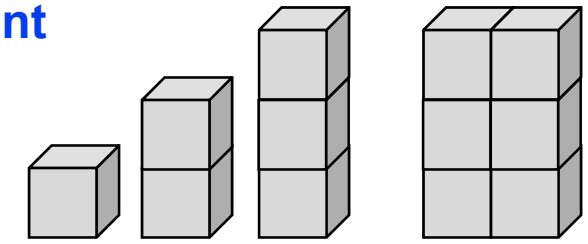
Background

- Started in 1999 by Stanford University and Cal Poly Teams
- Created 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 commercial components
    - Solar cells, batteries, radios, etc.
  - Self-imposed safety standards
- Defines Shape, Size, Mass, and Interfaces
  - 10 cm cube, 1-1/3 kg
  - Supported by corner edges
  - Specifies materials and tolerances
- Outlines Initial On-Orbit Operations
  - Restrained deployables
  - Initial communication
- Simple Document



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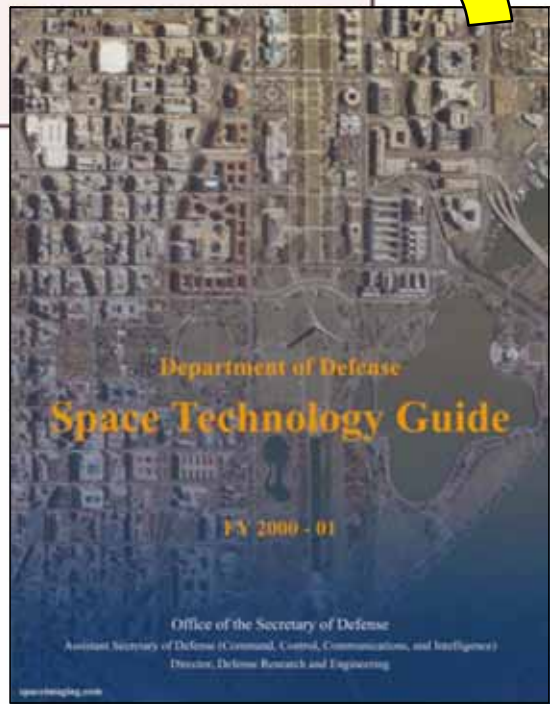
A Common Question Asked…

"What's The Definition of a Nano-Satellite?"

- **Definition Offered for Satellite Classes:**

For the metric challenged: 1 kg = 2.2 lb

The term "microsatellite," or "microsat" for short, has become a generic reference for entire new classes of satellite whose size and weight reduction from traditional satellites may be measured in orders of magnitude. Their specific nomenclature derives from their mass, as follows:	• Traditional satellites weigh upwards of 1,000 kg, and require medium or large launch vehicles to boost them into orbit • Smallsats weigh on the order of 500 kg, and are defined as fitting on the smallest class of launch vehicles • Microsats generally range from 100 down to 10 kg • Nanosats range from 10 down to 1 kg • Picosats weigh less than 1 kg.



CubeSats are a *Specific Configuration* of NanoSats

- **For the Hard Core Supporter of Even Smaller Satellites …**
  - ***"FemtoSat "*: 100 g to 10 g**
  - ***"AttoSat"* : Less than 10 g ⇨ *"The Sugar Cube-Sat"***

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The P-POD CubeSat Dispenser

- Enables Standard Common Interface to Multiple Launch Vehicles

- **P-POD Design Objectives:**
  - **Safe and reliable deployment**
  - **Compatibility with many launch vehicles**
  - **Simple design**
  - **Protect launch vehicle and primary payload**
- **Accommodates 3 Single ("1U") CubeSats**
  - **Or one 3U, or two 1-1/2U CubeSats, etc.**
- **Rectangular Tubular Enclosure**
  - **Fully encloses CubeSats**
  - **Access panels**
- **Simple Spring Assisted Ejection**
- **Commonly Used Deployment Initiator**
  - **Facilitates easier interfacing to Launch Vehicle**
- **Redundant Switches Verify Deployment**

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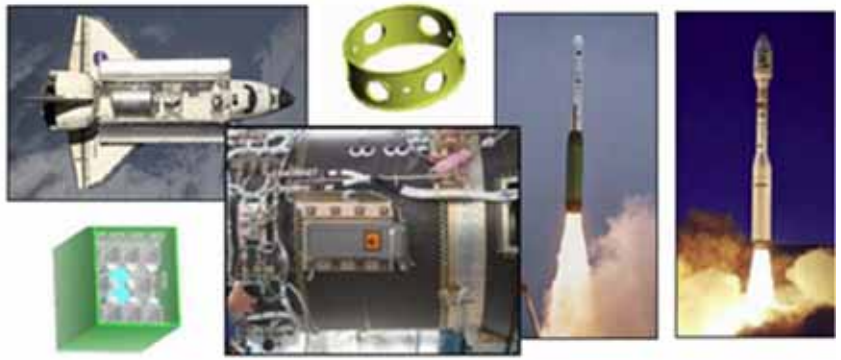
CubeSats Provide “Containerization” and Standard Interfaces

A Revolution in <u>World-Wide</u> Transport



A Revolution in <u>Space</u> Transport

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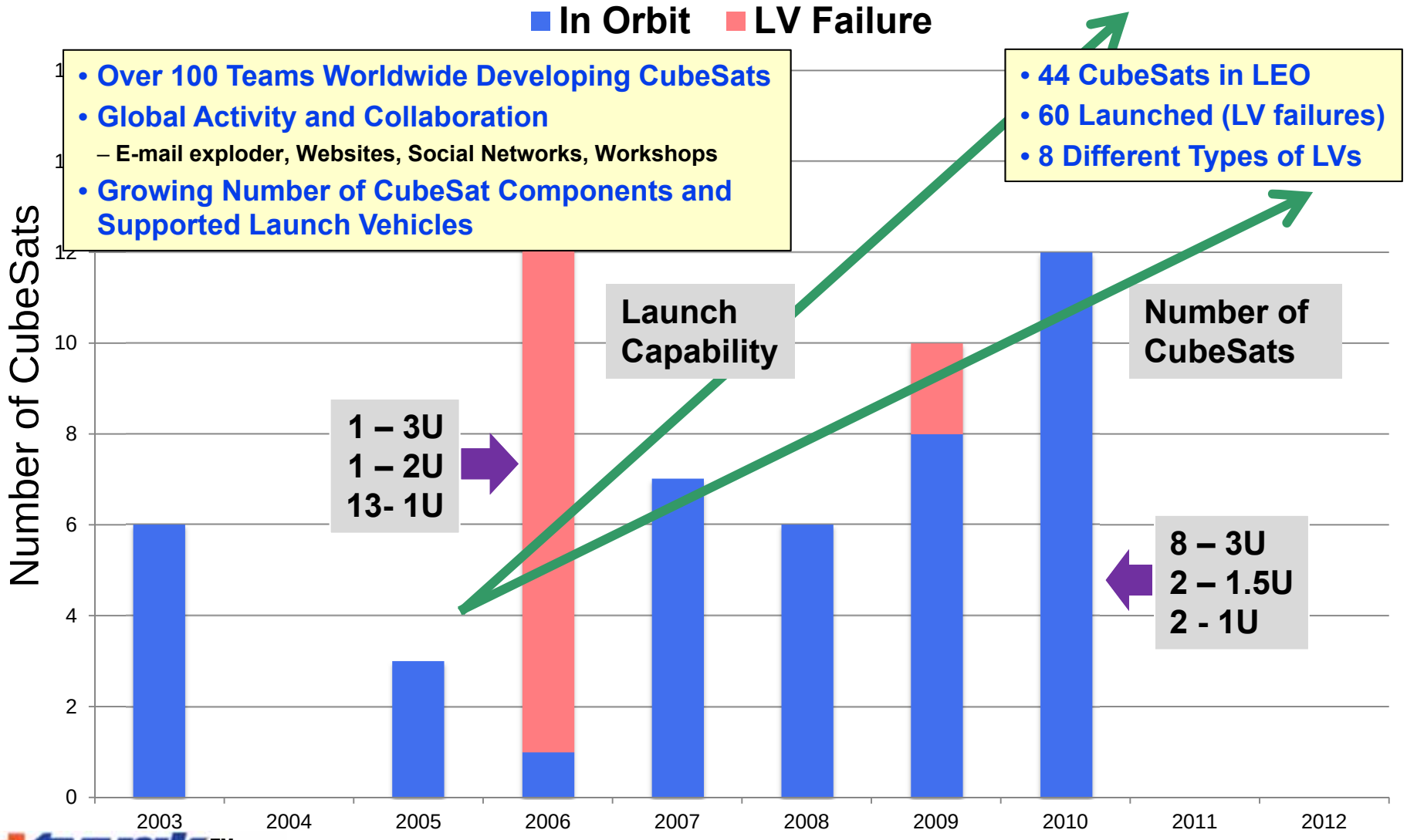
CubeSat Flown to Date and Launch Trends



LV = Launch Vehicle

Why Has CubeSat Been a Successful Standard?

- **Enables Very Low-Cost to Build and Launch**
  - Acceptance of greater risk → Inspires creative approaches
    - Reduced "Cost of Failure"
  - Avoids spiral of higher cost ⇔ higher reliability
- **Rapid Development Cycles Accelerates System Maturity**
- **Leverages Advances in Low Power, Miniature Electronics**
  - Worldwide R&D investment dwarfs Aerospace R&D expenditures
- **Internationally Recognized Standard**
  - Worldwide development activities and launch opportunities
- **Primary Spacecraft and Launch Vehicle Protected**
- **Spacecraft Built Independent of Launch Vehicle**
  - Enables "Off-the-Shelf" CubeSat; build without firm launch
  - Interchange spacecraft between Launch Vehicle's
- **Decoupling Spacecraft ⇔ Launch Vehicle Manifest**
  - Launch Vehicle manifest without firm spacecraft

CubeSats Bring a New Paradigm to Space

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Representative Costs Associated with CubeSats

- Costs Significantly Effected By Mission Assurance Requirements

Program Phase	Class D	Class C	Class B
Design, Fabricate, Assemble, and Test [1]	**$200k - $500k**	**$300k – $1,000k**	**$750k – $2,000k +**
Launch [2]	**$180k - $250k**	**$200k – $350k**	**$200k - $350k**
Operate On-Orbit [3]	**$10k - $25k / month**	**$25k – $75k / month**	**>$100k / month**
Overall Program Cost [4]:	**$500k - $1,000k**	**$800k - $2,250k**	**$2,150 - $3,550k**

Mission Class Definitions:

Class D: "Minimum Acquisition Cost"

Class C: "Economically Reflyable or Repeatable"

Class B: "Risk with Cost Compromises"

Reference: DoD-HDBK-343 *"Design, Construction and Testing Requirements for One of a Kind Space Equipment"*

Notes:

1) First unit cost for a 3U CubeSat. Does not include cost of payload. Generally a flight unit and spare are fabricated, plus some additional test units and components. Significant economies of scale exist.
2) Launch costs for domestic and foreign opportunities.
3) Operations costs are higher for initial weeks and months. Significantly driven by Ground Segment infrastructure.
4) Approximate overall program (without payload) for one year mission.

All Costs Approximate !

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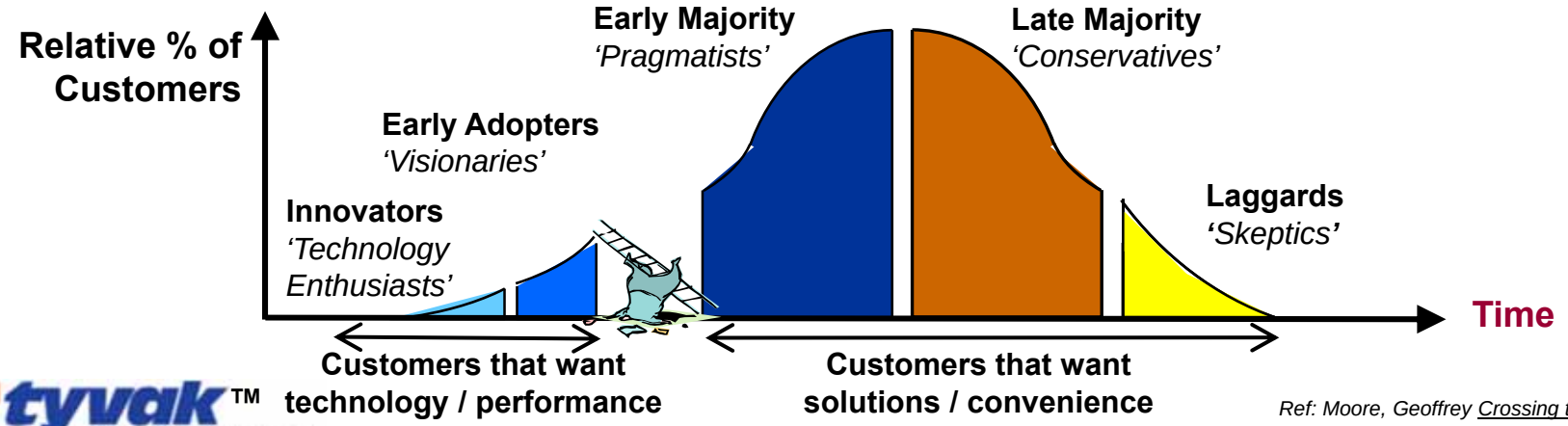
Uses for CubeSats Undergoing Shift and Diversification

- Natural Evolution as Technology Matures

- **CubeSat Principles Were Built Upon Low Costs and Short Schedules 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 Evolving To The Point Where People Are Thinking of Real Applications (*Pragmatists*)**
  - **Have we crossed the technology chasm?**
- **Diversification is Evident with Growing Variation of Educational & Industry Applications, and Government Funded Programs**
  - **For Example: NSF Space Weather, NRO Colony II Bus, SMC/XR SENSE, GAINSTAM Workshop**



Ref: Moore, Geoffrey Crossing the Chasm

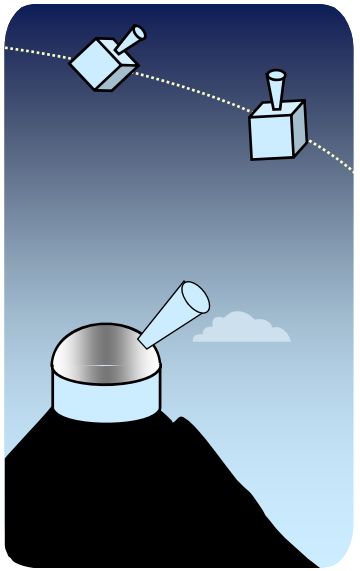
How Do We Measure the Utility of CubeSats?

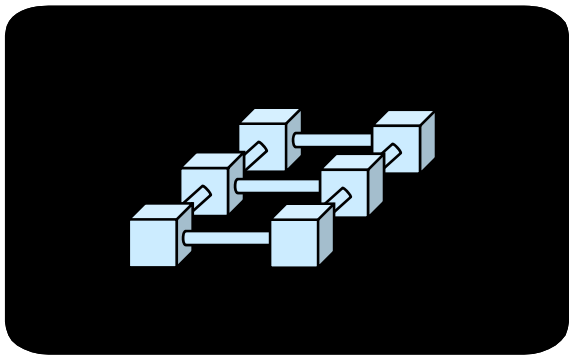
- How Do We Exploit the Strengths of CubeSats?

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

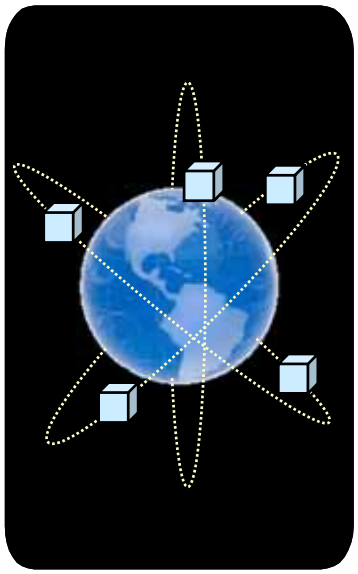
- **Key Attributes of NanoSats**
  - **Less expensive to build and launch**
  - **Deploy in quantity**
  - **Small size**

Operate in Proximity
- Resolution
- Availability
"A 5 inch television looks like a big screen when you are sitting 15 inches away"





Modular, Reconfigurable Vehicles and Arrangement
- Adaptability
- Flexibility
"Lego-Sats"



Deploy Constellations of Vehicles
- Coverage
- Availability
"Timely coarse data can sometimes be more important than high-fidelity, dated data"

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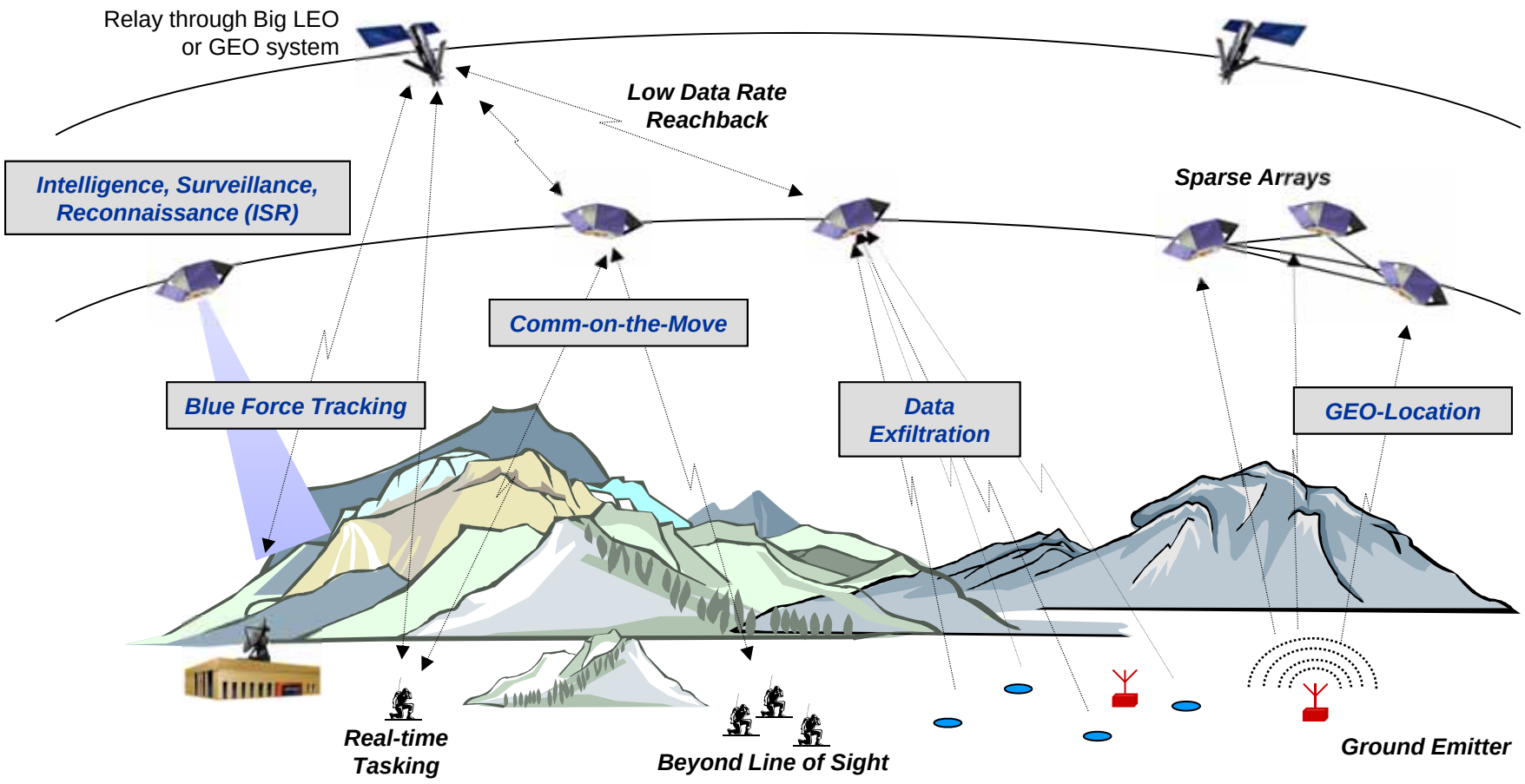
Some Characteristics of Candidate CubeSat Missions

- For "Ground Focused" Missions

- **Low Duty Cycle, Specific "Niche" Missions**
  - **Operating for short durations, over specific locations, or at specific times**
  - **Generally used to augment and complement other space and ground systems**
- **Persistence Over Key Ground Areas**
  - **Constellations of CubeSats to enable 24/7 coverage**
  - **Ground coverage for specific areas (latitudes) of interest**
- **Leverage Real-Time Command and Control**
  - **Responsive tasking to address emergent needs**
- **Respond to Changing and Emerging Events Worldwide**
  - **Assemble and launch for quick reaction capability**

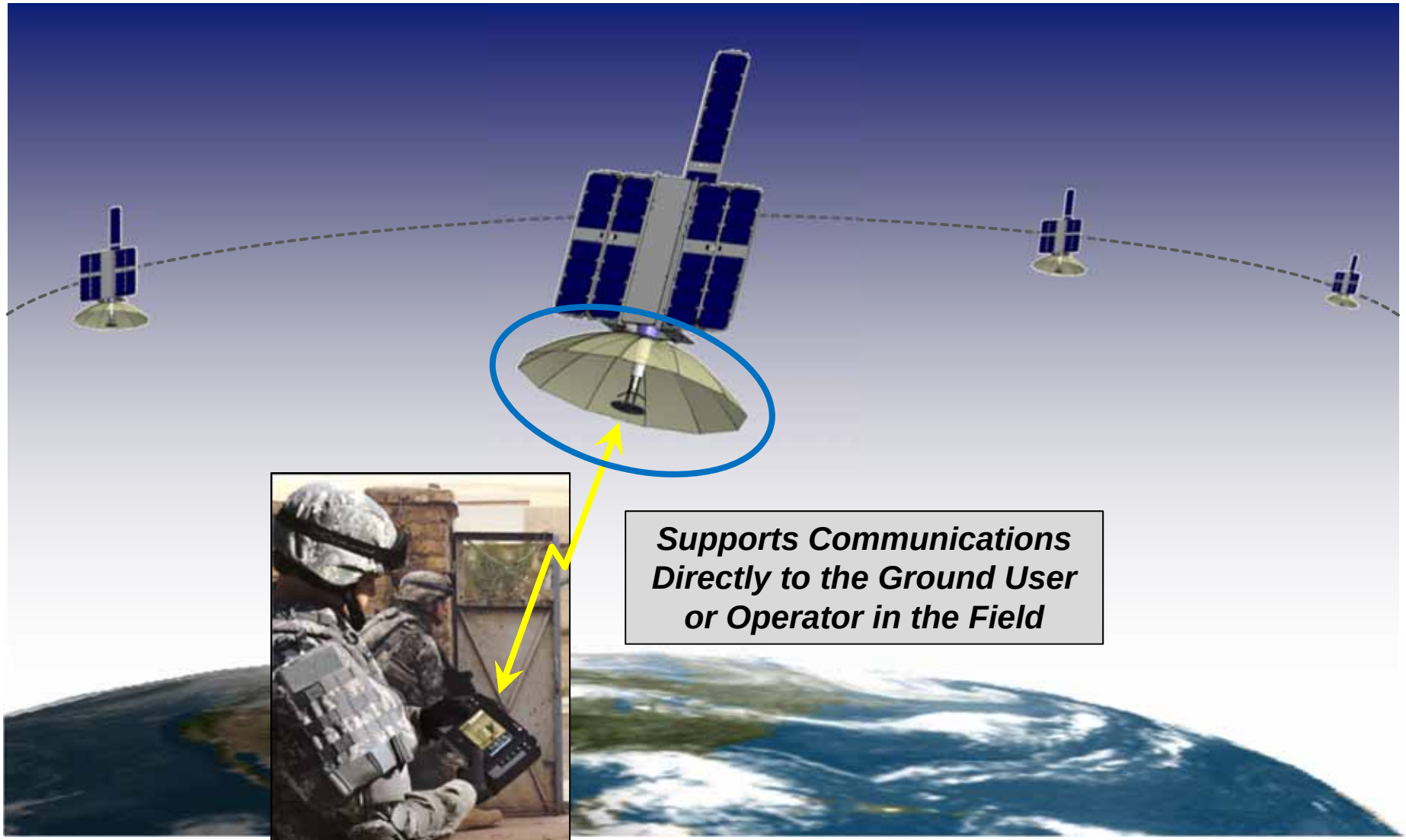
Representative “Ground-Focused” Missions

- Examples From a Much Larger Set of Candidate Missions



Innovative Technologies Enable New CubeSat Missions

- Miniature Deployable High Gain Antenna



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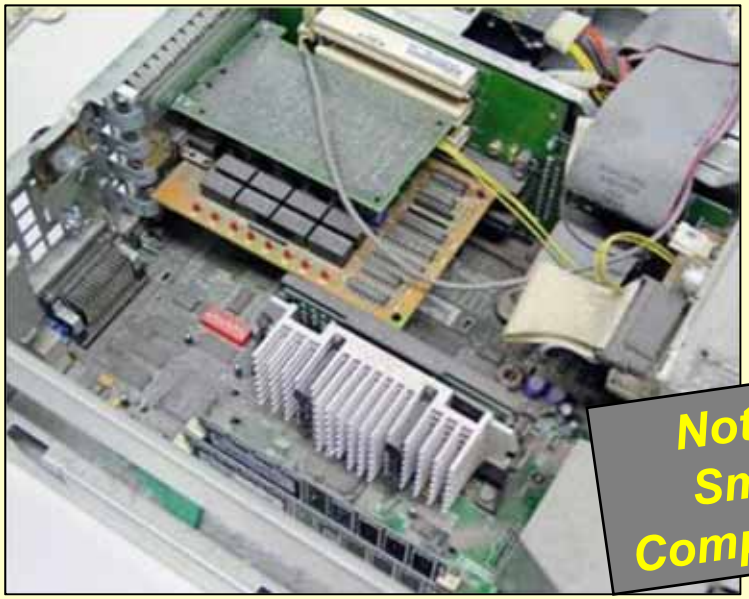
Unique Needs of Miniature, High Performance Systems

- A Different Design Approach is Required

- **Miniaturization Requires a Highly Integrated System Solution Approach**
  - **Can't just bolt together group of disparate components**
  - **Need to be designed as an Integrated System**
  - **Kit and Modular approach can support low tech needs, but not high performance**
- **Analogous to…**

- **Personal Computer**
  - **Plug and Play allows for rapid customization by end user, however is highly inefficient packaging**



- **Laptops and Smartphones**
  - **Specialized components and design approach needed to provide highly efficient packaging**

Not Just Smaller Components!

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Overview of NanoSpace

- The Path to Operationally and Scientifically Relevant CubeSat Missions

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DRIVERS

"What are the key problems"

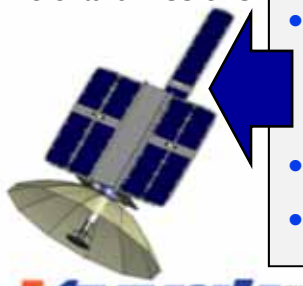
- **"Big" Space Budgets and Protracted Delivery Schedules Out of Control**
- **Shrinking Government Budgets**
  - Trying to do more, or maintain existing capabilities with less funds
- **High Cost of Launch Represents Significant Portion of Overall Program Costs**
- **Under-supported Niche and Complementary Missions (Due to Cost Constraints)**
  - LEO Constellations for persistent ISR, or multi-point in-space sensor platforms
  - Micro-Inspectors
  - Low cost experimental test beds

ENABLERS

"What's changed to enable a solution"

- **The CubeSat Standard**
  - New Paradigm in Low Cost Spacecraft
  - "Grass Roots" development activities
- **Standard P-POD CubeSat Dispenser**
  - "Containerized" approach to launch
- **Worldwide R&D Investment in Low Power Electronics**
  - Dynamic power micro-processers, and high efficiency power management
  - "Lightweight" operating systems and software development environments
- **Rapid Prototyping Fabrication**
- **Easy to Use and High Fidelity Simulation and Design Tools**

Operationally and Scientifically Relevant Missions



BARRIERS

"What are the remaining barriers to developing a solution"

- **Traditional Aerospace Industry Approaches to:**
  - Space Vehicle Design and Fabrication Processes *(to Enable Highly Integrated Vehicle)*
  - Program Organization, Processes and Execution *(for Short Schedules and Low Costs)*
- **Availability of Advanced Components for Needed CubeSat Missions**
- **Wider Acceptance that CubeSats Can Perform Substantive Missions**

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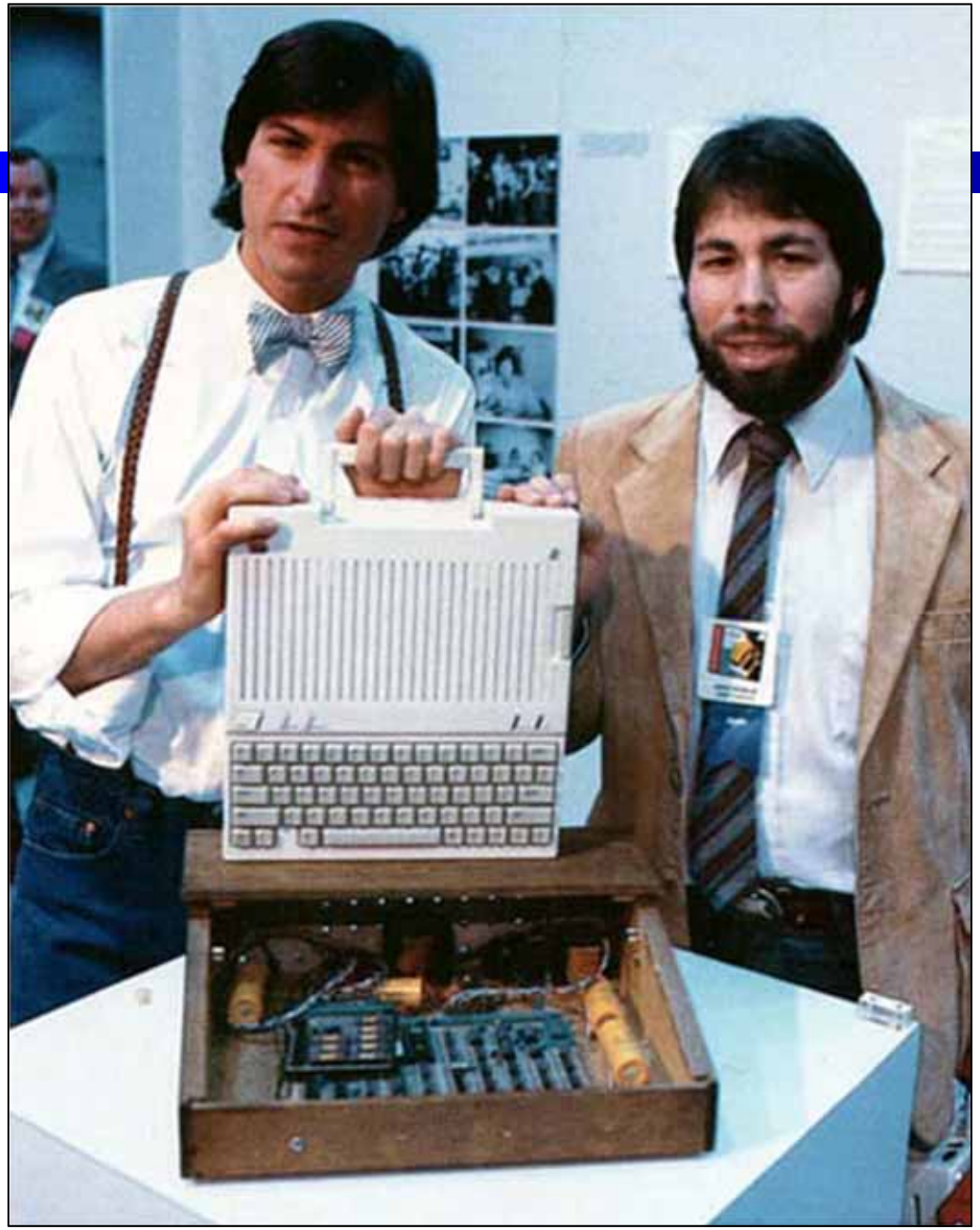
Some Thoughts on the Future of NanoSpace

- **See Many Parallels to Initial Personal Computer Genesis**
  - **Grass-roots "Homebrew Computer Club" origins**
    - **Highly interactive and sharing user community**
  - **Lower cost had strong end user appeal**
    - **Enabled direct end user control and operation**
  - **Performance growth driven heavily by technology advancement**
- **Do CubeSats Represent Disruptive Technology?**
  - **CubeSats have many representative traits, but too soon to tell**
    - **Aerospace industry operates at much slower pace**
  - **In search of the "killer app"…**
    - **Believe it will come from a market need outside current satellite uses**
    - **I have some ideas ☺**
- **CubeSat Growth Only Limited by Ability to Adapt Technology**
  - **Applicable technologies come from a variety of sources**
  - **A key Tyvak™ company focus is to leverage new technologies to develop CubeSats, subsystems and components that enable new missions**



"Stay Hungry. Stay Foolish."

Steve Jobs, 1955-2011

Thank You !