DoD Perspective on CubeSats

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Small Satellite Portfolio
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Integrity ★ Service ★ Excellence

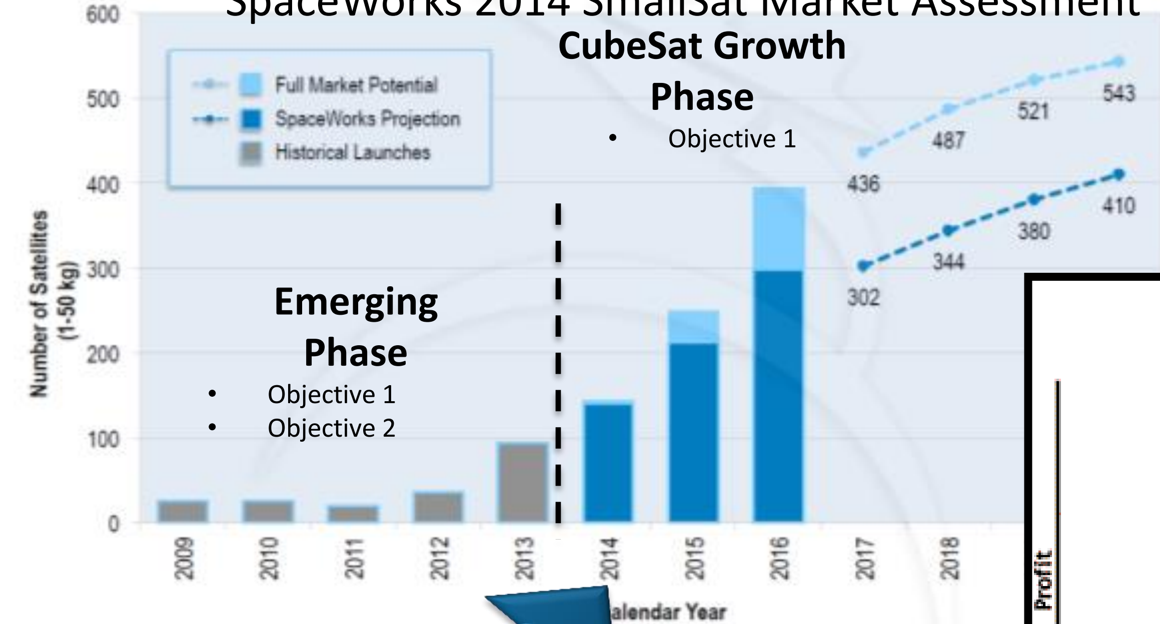
Note: The following slides are a compilation of publically cleared material. Additional information can be provided if requested and time allowed for the public release process.

Outline

- Overview
- Small Satellite Applications for S&T
- Small Satellite Applications for Operational Use
- Small Satellite Applications for Workforce Development
- Limitation of Small Satellites
- Summary

An exciting time for CubeSats

SpaceWorks 2014 SmallSat Market Assessment



CubeSat Growth Phase

- Objective 1

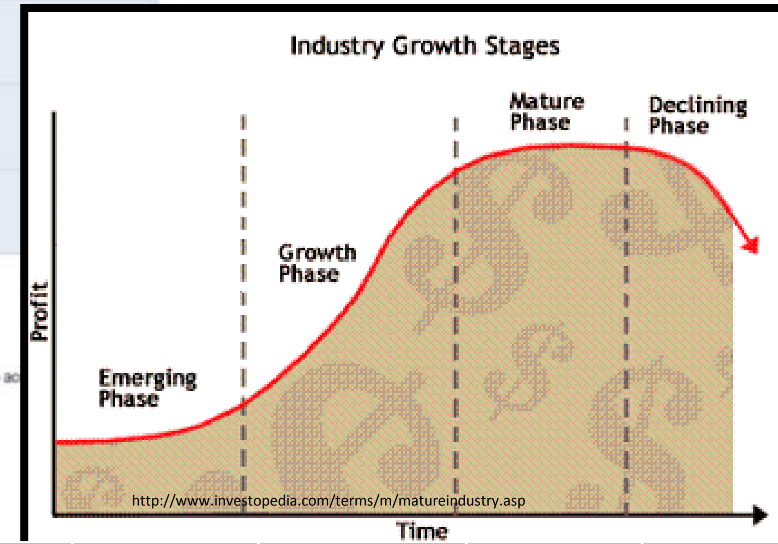
Emerging Phase

- Objective 1
- Objective 2

http://www.sei.aero/eng/papers/uploads/archive/SpaceW... ...ite_Market_Assessment_January_2014.pdf

Should the Air Force be interested in CubeSats? Absolutely!

Typical for new technology



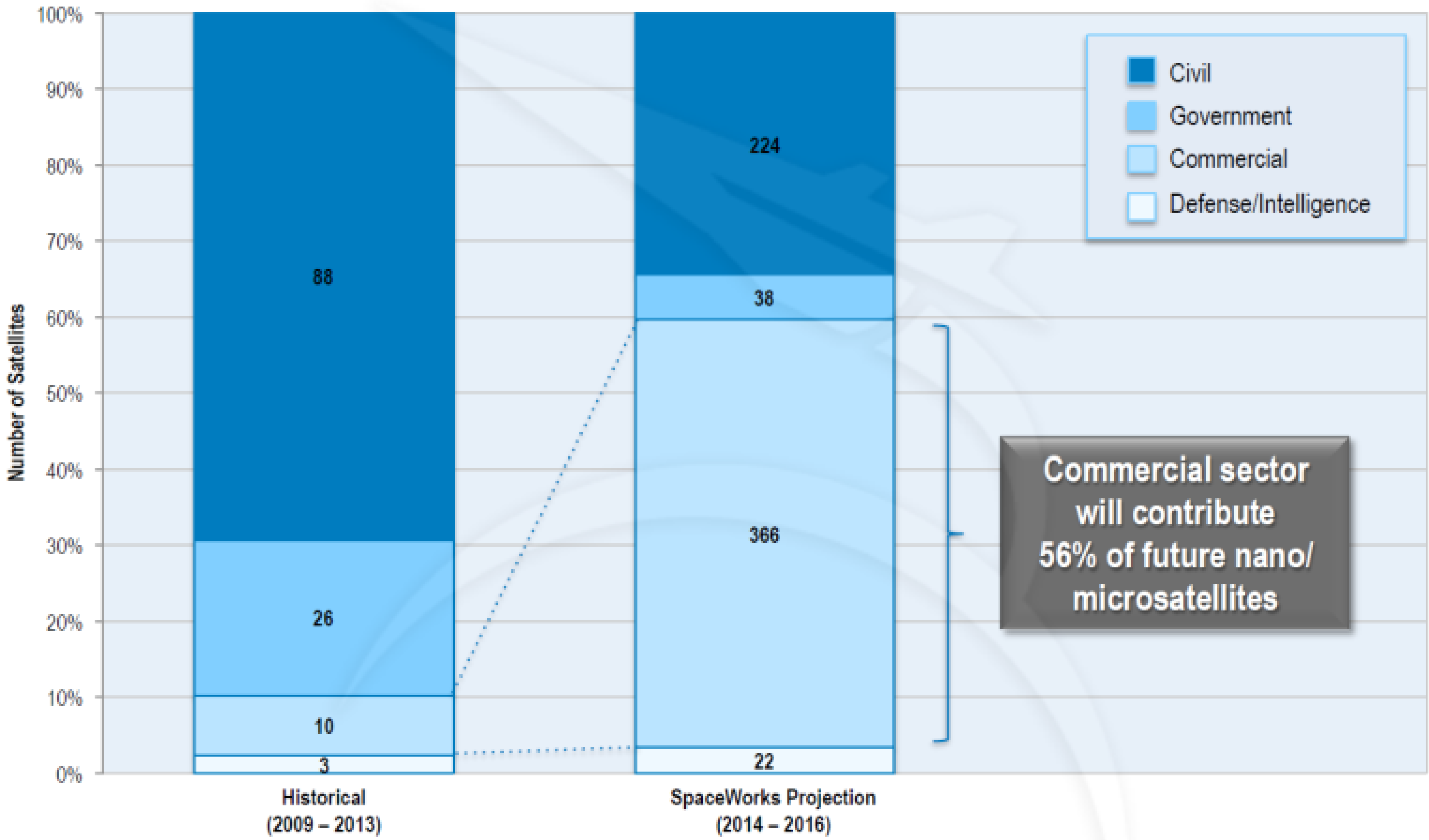
http://www.investopedia.com/terms/m/matureindustry.asp

	Emerging	Growth	Mature	Declining
Audience	Early Adopters	Mainstream	Late Adopters	Laggards
Market	Small	Growing	Large	Constricting
Competition	Low	Moderate	High	Moderate
Business Focus	Awareness	Market Share	Customer Retention	Transition
Design Focus	Tuning	Scaling	Support	Transition

www.thinkmarketingmagazine.com

Market Assessment

Nano/Microsatellite Trends by Sector (1 – 50 kg)



The civil sector remains strong, contributing over one third of future nano/microsatellites, but it will see reductions compared to 2009-2013 when the sector contributed 63%

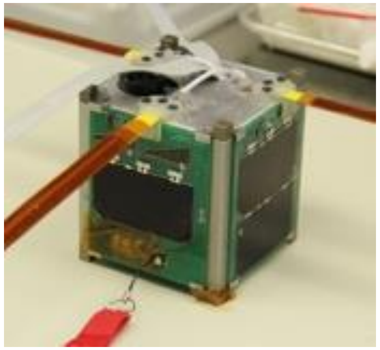
http://www.sei.aero/eng/papers/uploads/archive/SpaceWorks_Nano_Microsatellite_Market_Assessment_January_2014.pdf

Steve Jurvetson, 2014 SmallSat Keynote

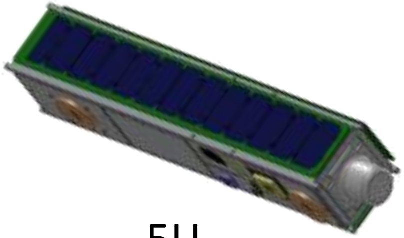
AFRL Portfolio Objectives

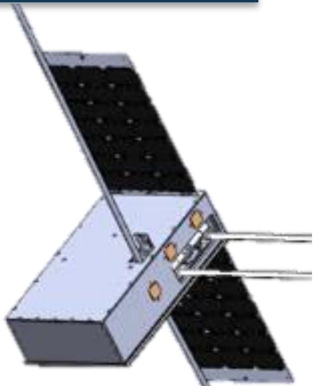
- **Objective 1: Determine how CubeSats can meet Air Force objectives (1kg-50kg)** ***What is the art of the possible?***
- **Objective 2: Workforce Development**

Objectives will be met through:
- researched performed at AFRL
- partnerships between AFRL and other government labs, industry, and academia
- At 2+ Cubesats per year


1U (10cm x 10cm)


3U


5U


6U

Small Satellite Applications:

Science and Technology

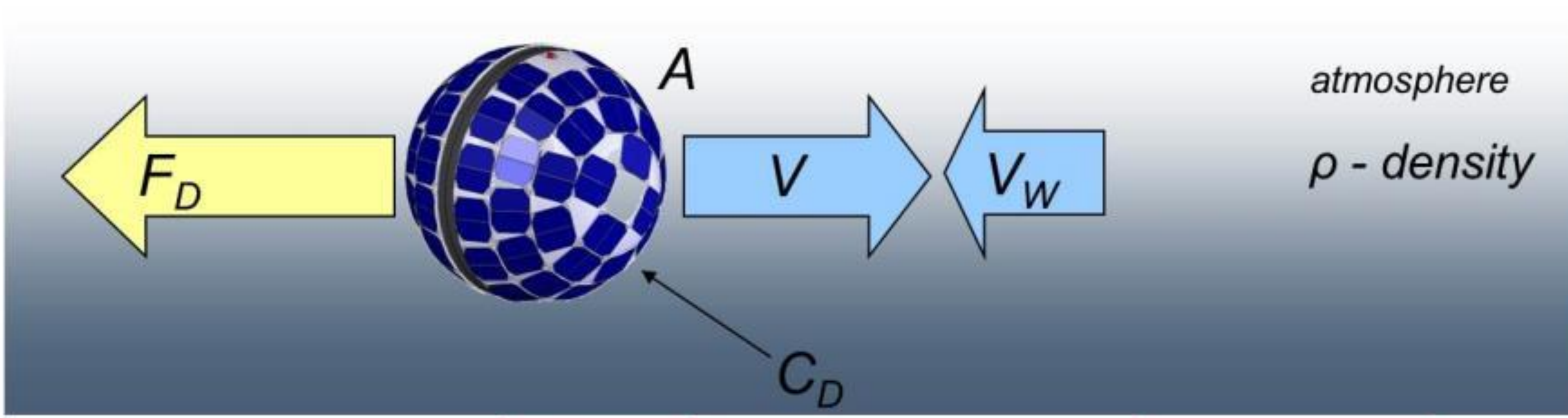
Note: All examples are from the University Nanosat Program

Science Investigations

- Small satellites excel at examining a particular, well-defined, science investigation (***Case Study 1***)
- Small Satellites can meet the need for multiple, in-situ measurements (global scale) needed for many space weather models (***Case Study 2***)

Case Study 1: DANDE	
Mission	Investigate atmospheric drag
Method	Spherical sat. with accels. and a neutral mass spectr.
Mass	43 kg
School	University of Colorado
Case Study 2: VPM	
Mission	Multipoint VLF wave and particle measurements
Method	6U CubeSat with particle detector payload
Mass	8 kg
School	AFRL

Case Study 1: DANDE



tracking

On-board NMS sensor

On-board accelerometers

$$F_D = \frac{1}{2}\rho \cdot C_D \cdot A \cdot (V + V_W)^2 = M \cdot a$$

measured

a priori

solution

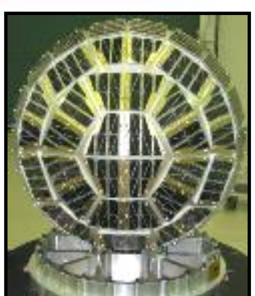
solution

solved

a priori knowledge

a priori knowledge comparison

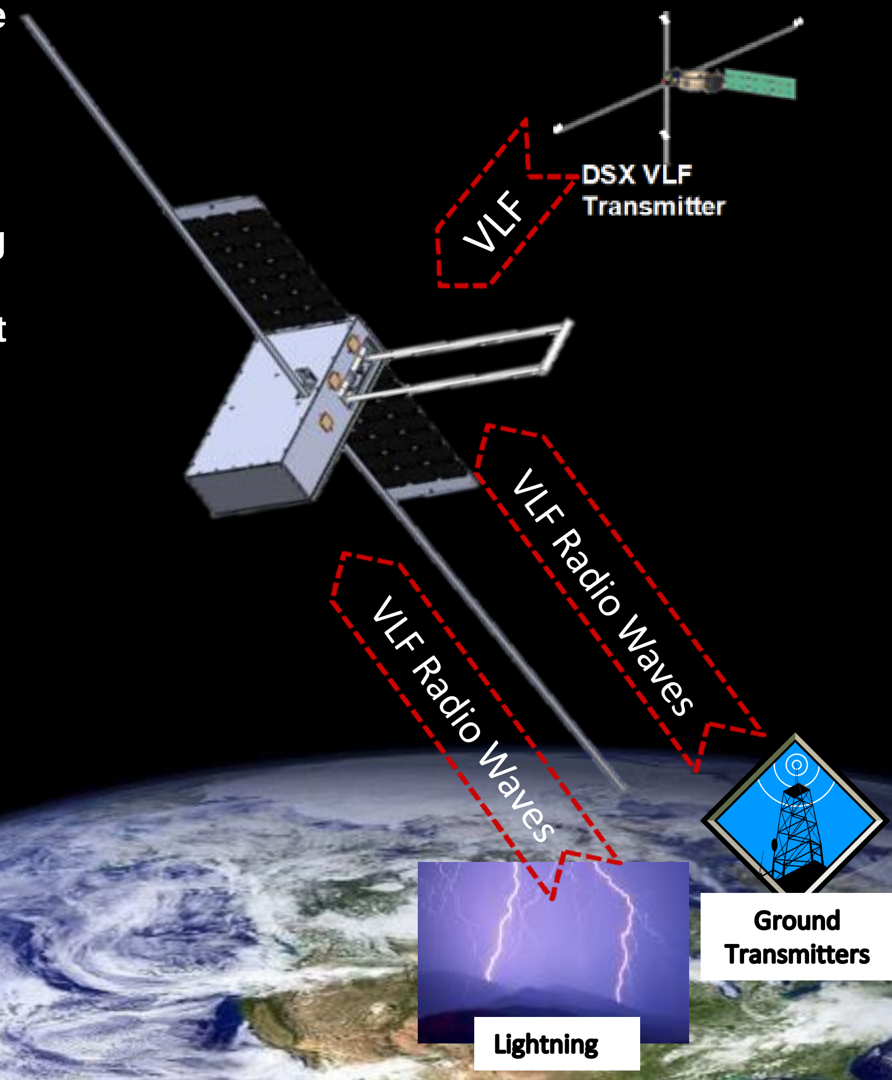
a priori knowledge



Able to investigate all aspects of the drag equation

Case Study 2: Very low frequency Particle Mapper (VPM)

- Critical augmentation for the AFRL Demonstration and Science Experiment (DSX) satellite
- Answers key DSX physics: Can we transmit VLF across the space plasma sheath into the far-field.
- Sensors to observe precipitating energetic particles induced by DSX
- Launch through DoD Space Test Program
- STATUS: 2016 Launch



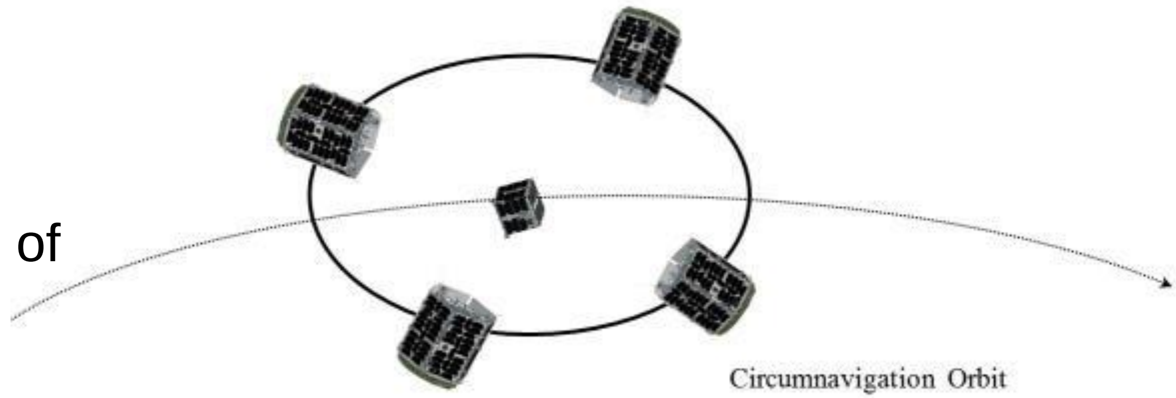
Technology Demonstrations

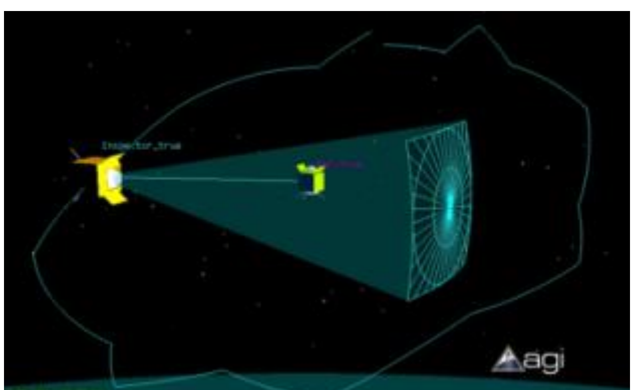
- Small Satellites provide a low-cost testbed for evaluating new algorithms (***Case Study 3***)
- Small Satellite provide opportunities for risk reduction of components for high value programs (***Case Study 4***)
- Small Satellites enable future missions (***Case Study 5***)

Case Study 3: M.Sat	
Mission	Circumnavigation of RSO
Method	Two small sats one with stereoscopic imager for prox-ops
Mass	~50 kg
School	Missouri S&T
Case Study 4: GEARRS	
Mission	Demonstrate Commercial C2
Method	3U CubeSat with Globalstar radios
Mass	3.9 kg
School	AFRL
Case Study 5: P-Cube	
Mission	Demonstrate Precision Timing between ground and CubeSats
Method	1U flying atomic clock, corner cube
Mass	2 kg
School	University of Florida

Case Study 3: M. Sat

- Visual Based proximity operations to autonomously circumnavigate an RSO (Mrs. Sat)
- Investigating stereo imaging
- Investigate 3D reconstruction of objectives

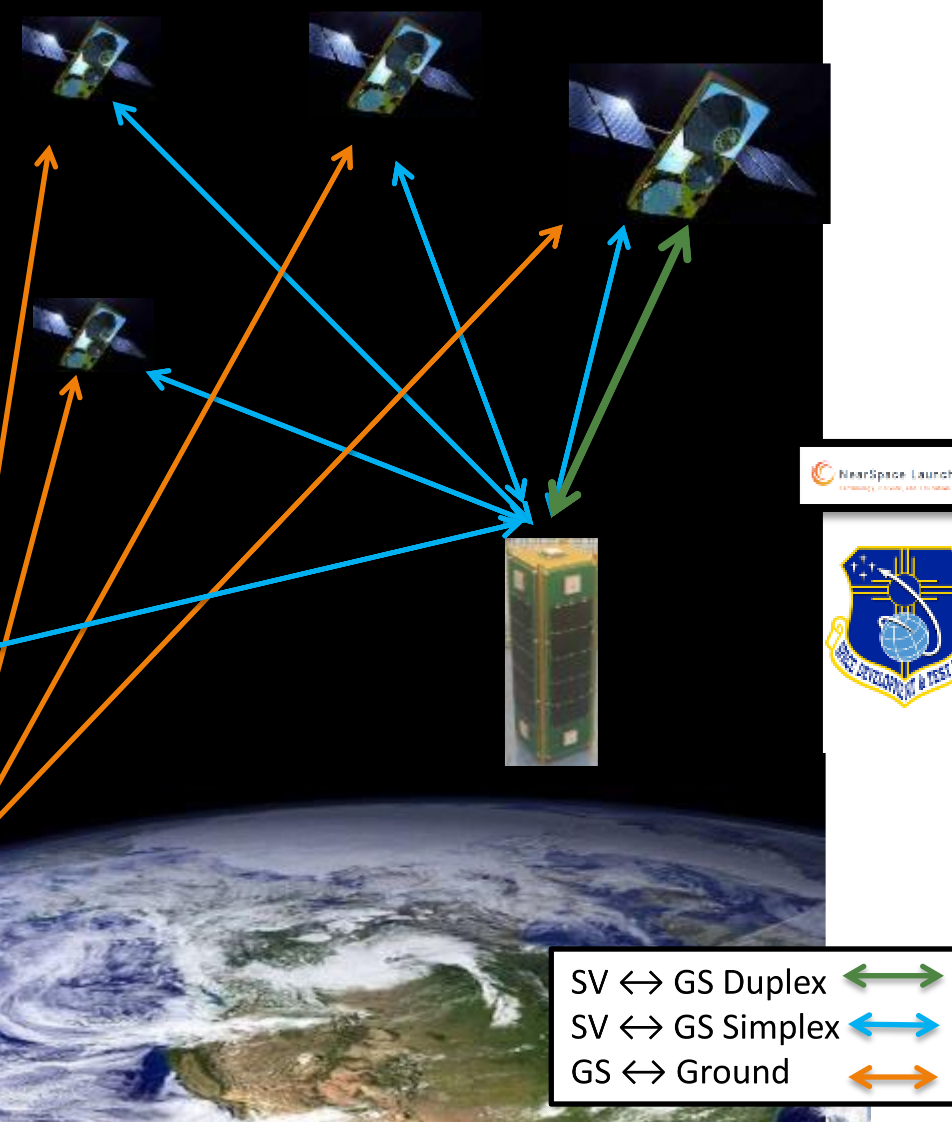


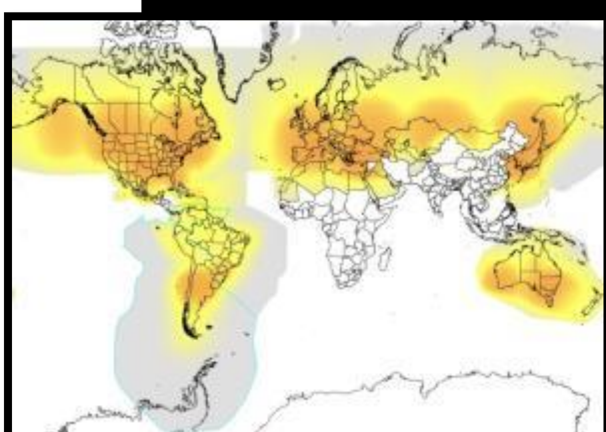


Allow research for on-orbit validation of next generation Prox-OPS

Case Study 4: Globalstar Experiment and Risk Reduction Satellite

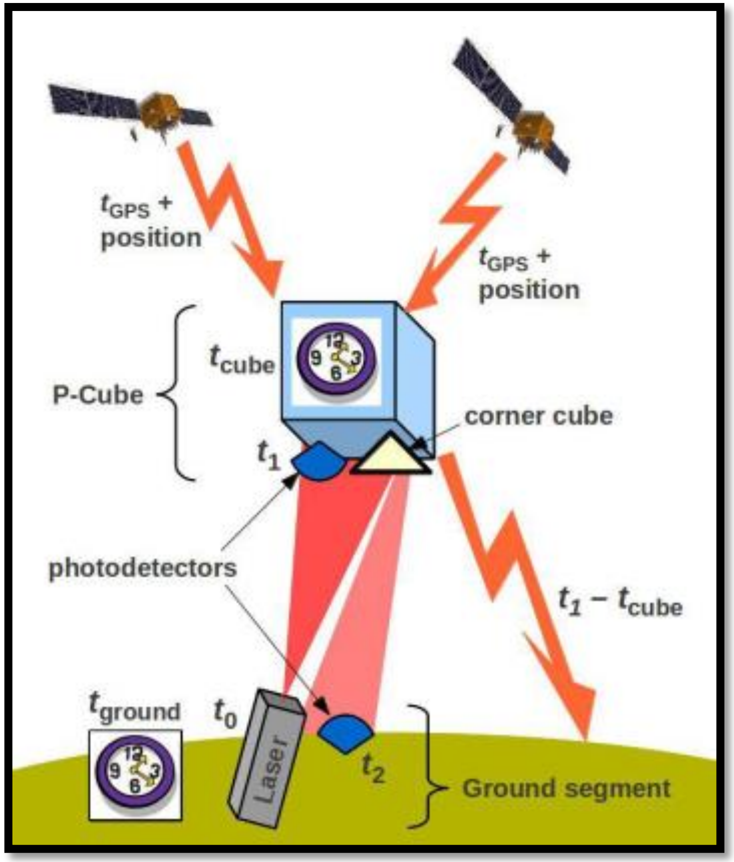
- Challenge: Can we use commercial comm to operate AF spacecraft?
  - Potential lower cost than current AFSCN
  - 60% global coverage for duplex
- Experiment: Characterize the Globalstar network for LEO spacecraft comm for both the Duplex and Simplex radios
- Mission definition to delivery in 94 days!
- Status: Launched to ISS in July 2014. Waiting to be deployed from station



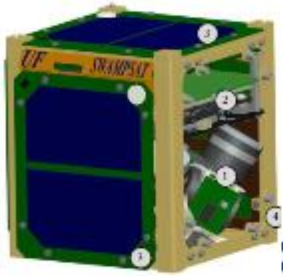


Case Study 5: P-Cube

- Precision Time Transfer with CubeSats
- Enable high accuracy timing between CubeSats and the ground
- Flying Symmetricom's Chip Scale Atomic Clock
- Use laser pulses and a corner cube to determine timing difference between the CubeSat and the ground (frequency stability on the order of ~1.5×10^{-10})
- Currently being developed by the University of Florida in the NS-8 competition



Enabling technology for disaggregated architectures



Small Satellite Applications:
Operational Use

Operational Applications

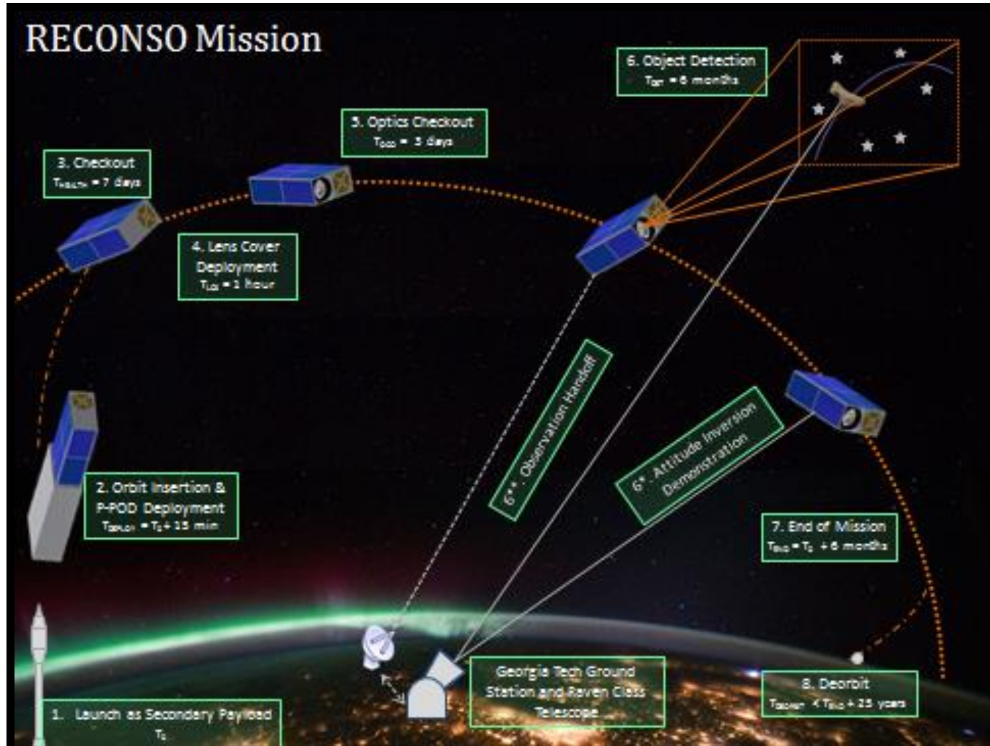
- Small Satellites can offload some of the work from operational high value assets allowing them to be allocated to critical areas of interest (***Case Study 6***)
- Small Satellites can perform routine missions for operational customers (***Case Study 7***)

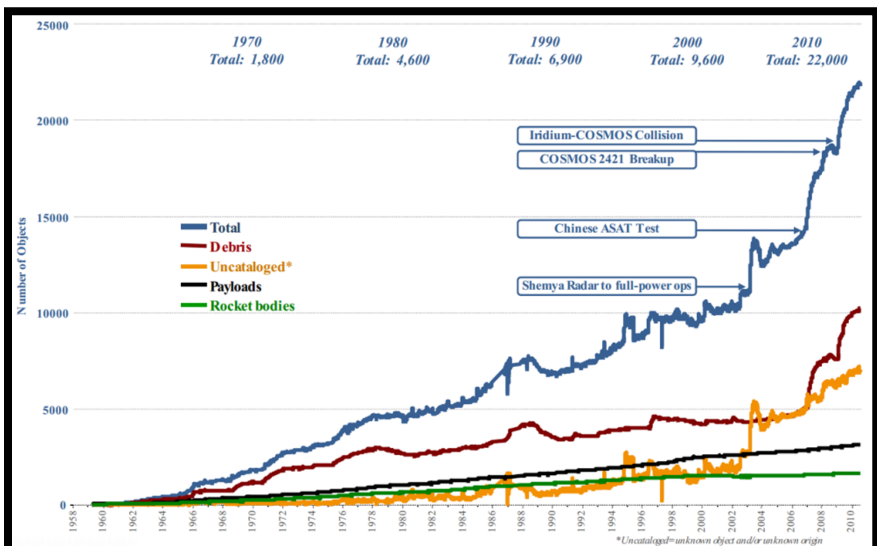
Case Study 6: RECONSO	
Mission	Investigate object detect and track of space debris
Method	6U with imager and
Mass	9 kg
School	Georgia Tech
Case Study 7: SHARC	
Mission	Provide radar calibration for ground based radars
Method	5U Cubesat with transponder and GPS
Mass	5 kg
School	AFRL

Note: Operational applications is not a goal of the University Nanosat Program

Case Study 6: RECONSO

- Operational augmentation
- Perform object detect and track to help characterize space debris
- RECONSO would allow for missions such as the Space Based Surveillance System (SBSS) to be dedicated to primary areas of interest

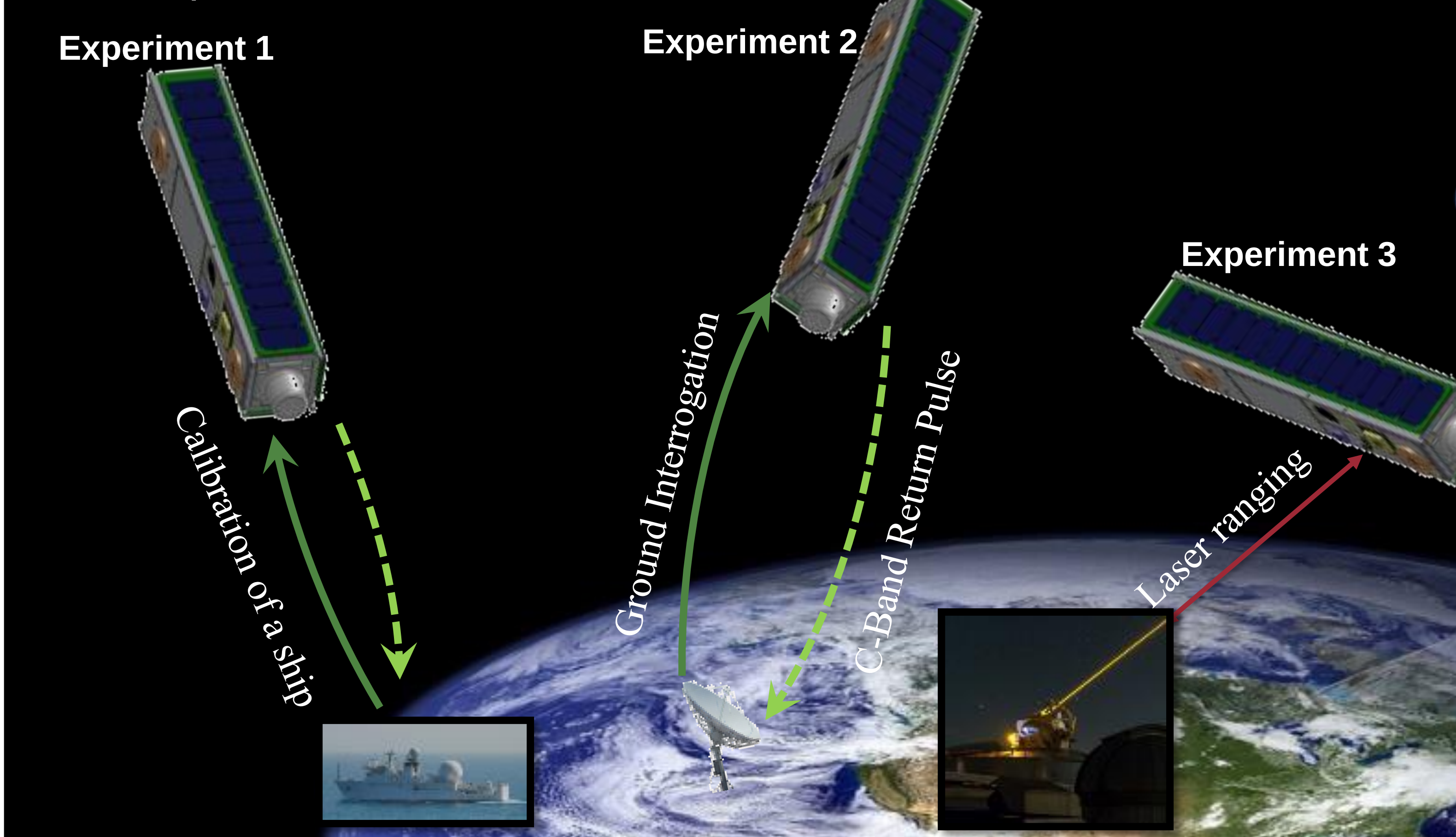




Low-cost missions such as RECONSO moves us towards a more complete space debris characterization

Case Study 7: Satellite for High Accuracy Radar Calibration

- Demonstrate the capability to perform critical calibration of over 120 Tri-Service C-Band radars.
- Calibration is needed to meet tracking requirements of orbital objects
- Demonstrate low latency delivery of data (min vs days)
- Investigate the performance of Hypervisor on-orbit for DARPA
- Launch: April, 2015



Small Satellite Applications:
Workforce Development

Workforce Development Needs

- **U.S. Space Policy (NSPD 49):** "… implement activities to *develop* and maintain highly skilled, experienced, and motivated space professionals within their workforce."

- **Rising above the Gathering Storm, Revisited (2010)**: "In 2000 the number of foreign students studying the physical sciences and engineering in United States graduate schools for the first time surpassed the number of United States students."

- **Preparing the next generation of STEM Innovators (NSF, 2010)**: "The identification and development of our Nation's human capital are vital to creating new jobs, improving our quality of life, and maintaining our position as a global leader in S&T."

Small Satellites and Workforce Development

- Small Satellite development efforts are a microcosm for large acquisition programs (still have BAA, hardware development, delivery, on-orbit operations)
- Small Satellites *typically* have
  - Shorter development lifetimes
  - Reduced set of requirements
  - Shorter lifetimes
- They provide an excellent opportunity for understanding the interrelated nature of requirements and how to trade them at the system level
- Programs are excellent for junior workforce development (both at the University level and the professional level)

The University Nanosat Program

- **University Nanonosat Program**
  - **Multi-year program to design, build, and fly a small satellite**
  - **Program has been around for 15 years**
  - **UNP provides an extremely high fidelity concept study to military relevant missions**
  - **Over 32 small satellite (50kg and down) missions have been investigated through the program.**
- **Roles and Responsibilities**
  - **AFOSR: Funds $55k per year up to four years**
  - **AFRL Space Vehicles:**
    - **Executes program (regular design reviews with each school)**
    - **Performs Environmental Stress Screening**
    - **Works with the Space Test Program for launch integration**
  - **SMC/Space Test Program: Launch**

NS8 Phase A (2013-Spring 2014):

10 University Missions

311 Student Participants
(26 grad / 285 undergrad)

32 Faculty / Staff

4 entries to juried publications

21 conferences papers

Primary Objective: Education

- Systems engineering training
- Workforce development
- Foundation for all UNP decisions

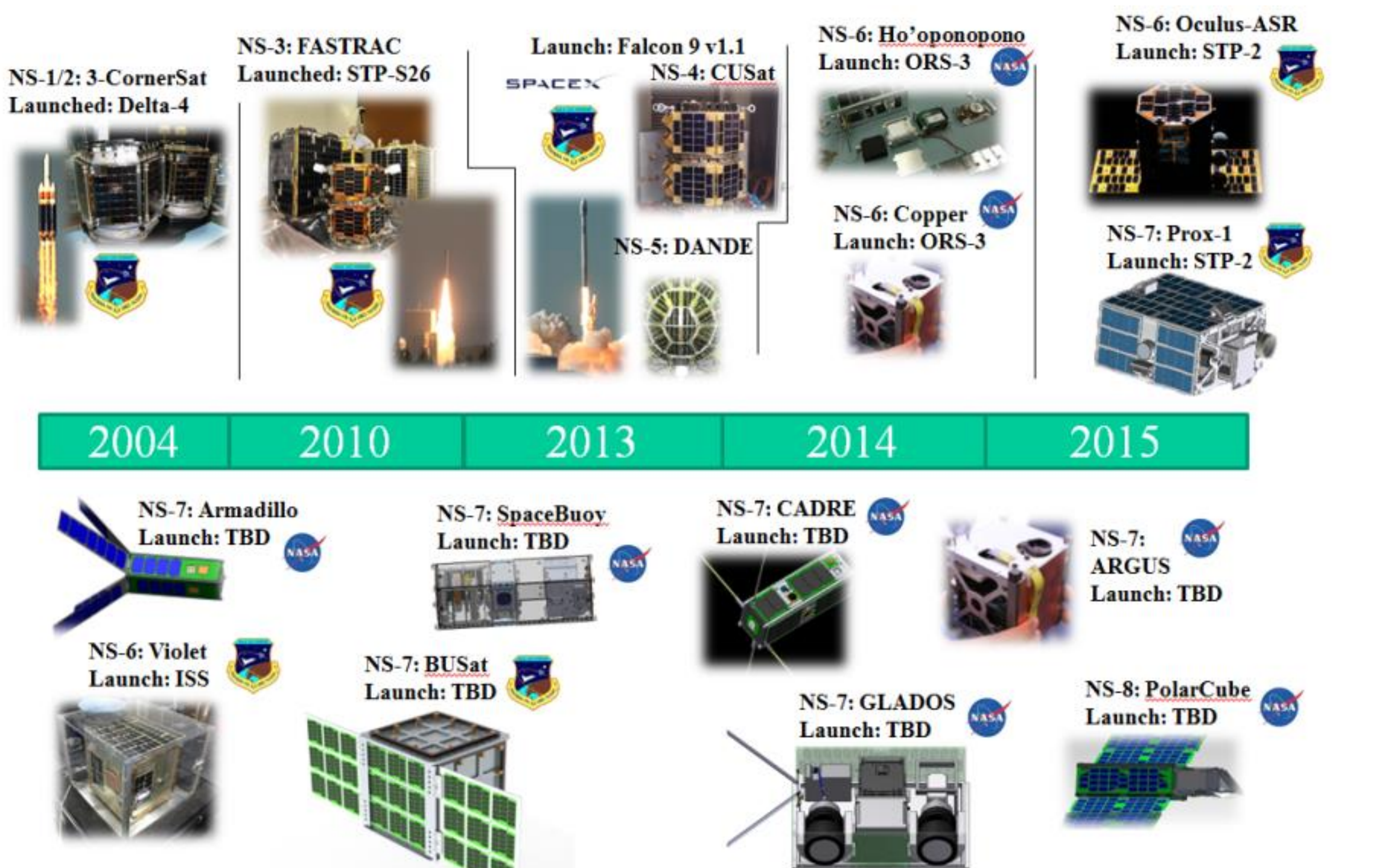
Secondary Objective: Technology

- Innovative, low cost technology development
- Motivation for Gov. and industry sponsors
- DoD relevant

Tertiary Objective: University Development

- Develop space hardware laboratories
- Support university PI's

UNP Background



Schools Involved in UNP

31 universities and ~5000 (undergraduate and graduate) students since 1999

5

Federally Recognized
Supporting National STEM initiatives

THE FEDERAL SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) EDUCATION PORTFOLIO

A Report from the
Federal Inventory of STEM Education Fast-Track Action Committee
Committee on STEM Education
National Science and Technology Council

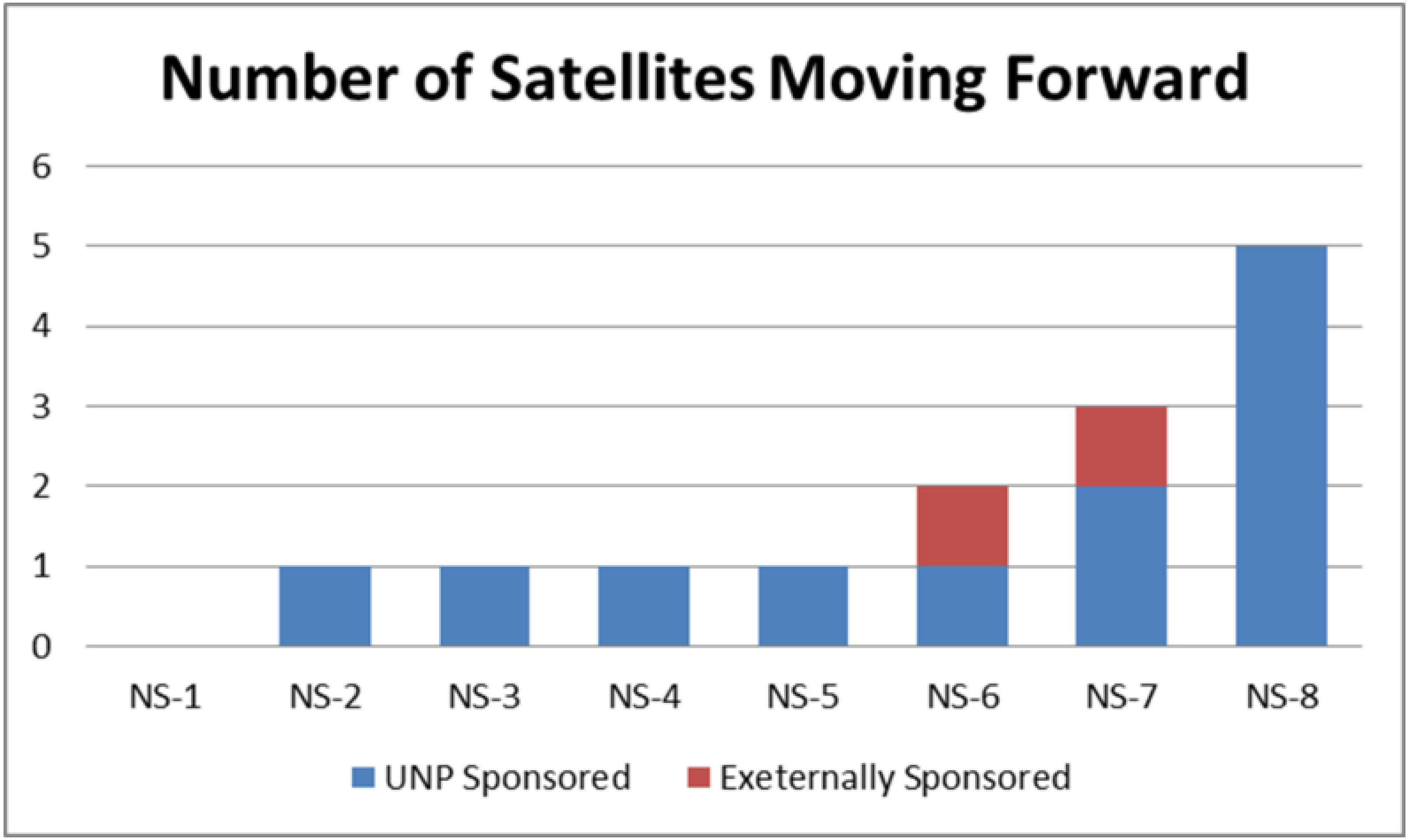
DECEMBER 2011

- Obj 1 • **Learning:** Develop STEM skills, practices, or knowledge of students or the public.
- Obj 1 • **Engagement:** Increase learners' interest in STEM, perception of its value to their lives, and/or their ability to participate in STEM.
- • **Pre- and In-Service Educator/Education-Leader Performance:** Train or retain STEM educators (K-12 pre-service or in-service, postsecondary, and informal) and education leaders to improve their content knowledge and pedagogical skills.
- Obj 1 • **Postsecondary STEM Degrees:** Increase the number of students who enroll in STEM majors, complete STEM credentials or degree programs, or are prepared to enter STEM careers or advanced education.
- Obj 1 • **STEM Careers:** Prepare people to enter STEM workforce with training or certification (where STEM discipline specific knowledge and skills are the primary focus of the education investment; STEM educator training and development investments should select the Pre-and In-Service Educator/Education Leader Performance objective listed above).
- Obj 2 • **Institutional Capacity:** Support advancement and development of STEM personnel, programs, and infrastructure in educational institutions such as universities, informal education institutions, state education agencies, and local education agencies.
- • **STEM System Reform:** Improve STEM education through a focus on education system reform.
- UNP • **Education Research and Development:** Develop evidence-based STEM education models and practices.

								Performance	
	Commerce	Total	59.20	65.96	72.79				
0128	Defense	University Nanosatellite Program	1.50	1.60	1.60	-	Agency Mission Workforce	Learning	No
0134	Defense	[illegible] and Support Undergraduate Research Experiences	4.50	4.50	4.50	-	Agency Mission Workforce	Post-Secondary STEM Degrees	No
0130	Defense	National Defense Education Program Science, Mathematics And Research for Transformation	19.00	33.00	47.00	-	Agency Mission Workforce	Post-Secondary STEM Degrees	No
0133	Defense	National Defense Science and Engineering Graduate Fellowship Program	33.09	36.34	36.81	-	Agency Mission Workforce	Post-Secondary STEM Degrees	No

UNP is recognized as a STEM program in the President's STEM educational portfolio

UNP Satellites Progressing Towards Launch



University Nanosat Program
A mature process

Phase A	Phase B	Phase C	Phase D
2 yrs Scheduled based reviews	~ 2yr Milestone based reviews	Launch dependent ~ 1 yr Milestone based reviews	< 1yr
Kickoff → CDR	CDR → ship to AFRL	Mission Assurance Testing (at AFRL) → Launch Veh.	Spaceflight (Launch through STP/NASA)
- U. Colorado-Boulder (NS8) - Boston U. (NS8) - U. Buffalo (NS8) - Embry Riddle (NS8) - Georgia Tech (NS8) - Missouri S&T (NS8) - Taylor U. (NS8) - U. of Florida (NS8) - UCLA (NS8)	- Michigan Tech (NS6) - Cornell (NS6) - Georgia Tech (NS7) - U. of Texas-Austin (NS7)	- No schools at this moment	Active: - Uof Texas-Austin (NS3) Complete: -Cornell (NS4) -U of Colorado-Boulder (NS5) -U. of Hawaii (NS6)

Small Satellite:

Limitations

Limitations of Small Satellites

- Power
  - Limitation: Typically are sub-50W with many missions sub-10W
  - Workaround: Duty Cycle payloads
- Communications
  - Limitation: Typically low baud rate communication systems (though changing)
  - Workaround: Creative CONOPS or large dish on the ground
- Multiple measurements
  - Limitation: Due to the low power, reduced volume this restricts the number of payloads a small satellite can fly
  - Workaround: Reduced size of payloads where appropriate
- Environments
  - Limitation: Very rough random vibration environments which we typically do not know at the outset of the program
  - Approach: Use GEVS model and over design (where appropriate)

Common Poor Approaches to Small Satellite Missions

- People attempt to cram a 500kg mission into a 50kg bus
  - Small satellite missions must be well scoped for the capability of the platform
- People assume just because it's small it's easy
  - Small satellites (especially Cubesats) are highly integrated systems
  - There are many interdependencies between systems
- People attempt to leverage big space approaches to small satellites
  - Small Satellites allow for new paradigms for acquisition, on-orbit operations and mission assurance

Conclusion

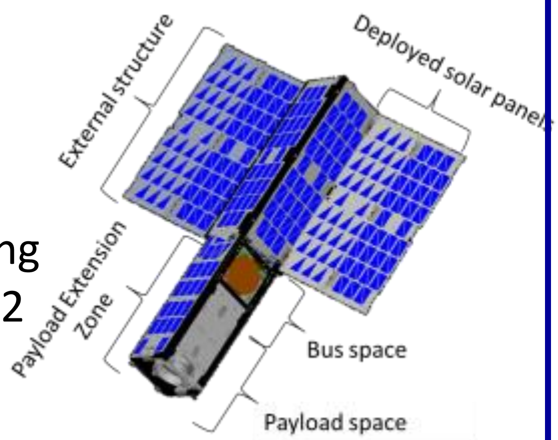
- Small Satellites can play a big part in meeting the needs of the Air Force S&T efforts
- The technology is currently available for tackling many of the space challenges
- Small Satellites can play a large role in helping to train the workforce to better manage large acquisition programs
- The mission must drive the CubeSat design (one size does not fit all)

Backup

NS-8 Technology Overview (1/3)

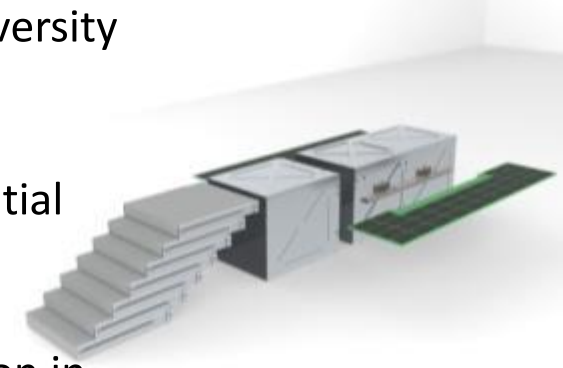
School: CU Boulder
Mission: **PolarCube**

Research Area: Tropospheric temperature sounding using the 118 GHz O2 resonance.



School: Boston University
Mission: **ANDESITE**

Research Area: spatial and temporal characterization of current filamentation in the Birkeland regions

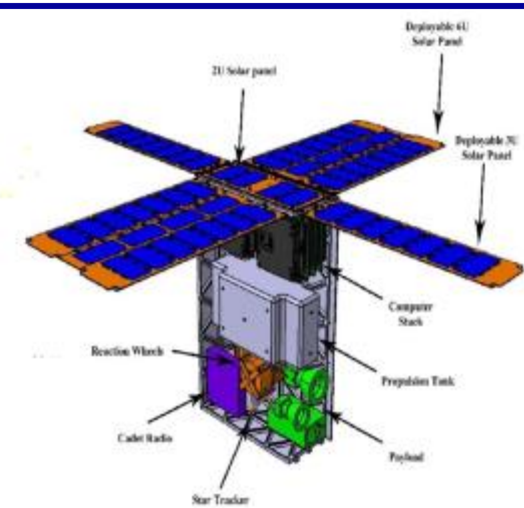


School: SUNY Buffalo
Mission: **LANSAT**

Research Area: Imaging deep space and resident space objects in geosynchronous orbit using visible and IR spectrum.

School: Embry-Riddle
Mission: **ARAPAIMA**

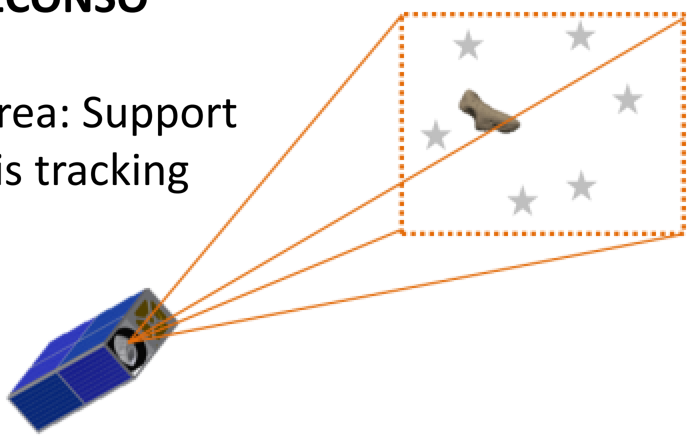
Research Area: Navigation, proximity maneuvering and 3D imaging for resident space objects (RSOs).



NS-8 Technology Overview (2/3)

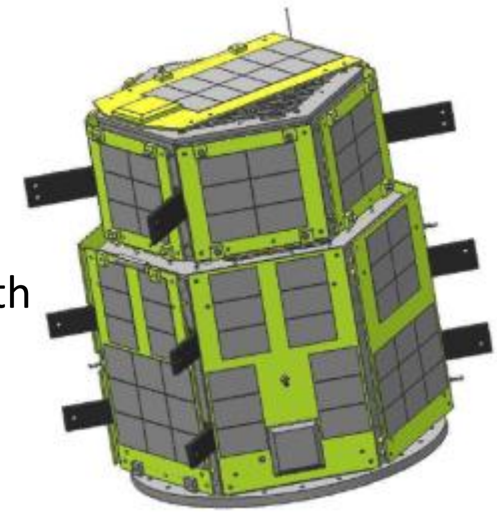
School: GaTech
Mission: **RECONSO**

Research Area: Support space debris tracking



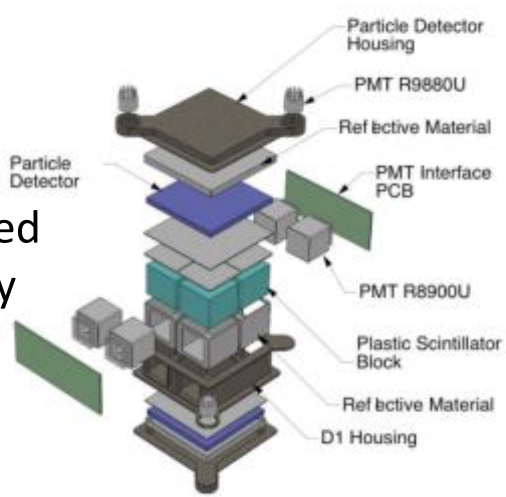
School: Missouri S&T
Mission: **M-SAT**

Research Area: Close proximity angles-only relative navigation with an untracked cooperative resident space object



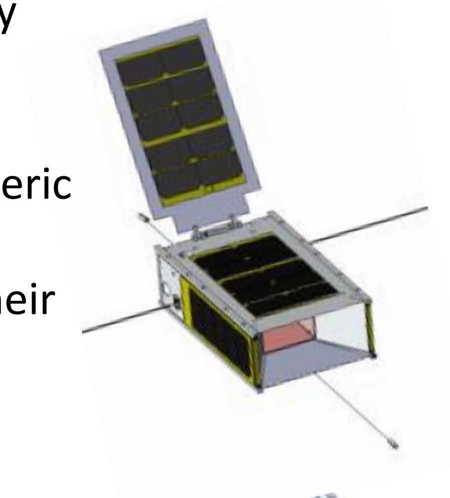
School: NMSU
Mission:

Research Area: Scintillator/SiPM-based neutron spectrometry in Low Earth Orbit.



School: Taylor University
Mission: **ELEOSat**

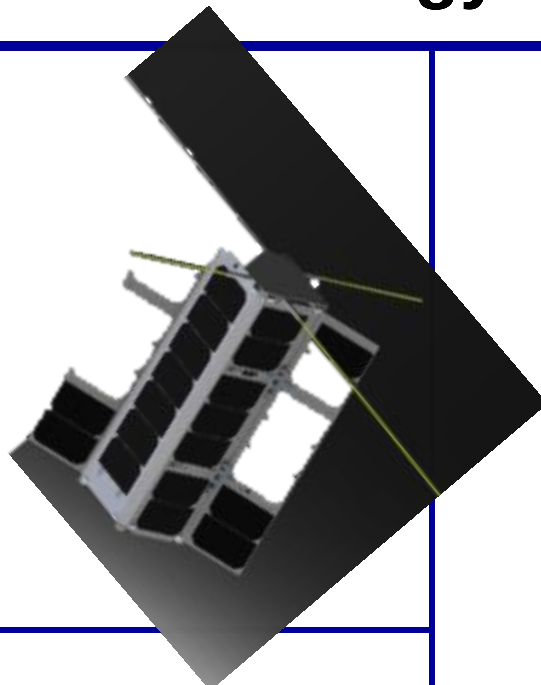
Research Area: Ionospheric structure, temperature, and composition and their effects on VLF transionospheric propagation.



NS-8 Technology Overview (3/3)

School: University of FL
Mission: **CHOMPTT**

Research Area: Precision time transfer between a CubeSat and satellite laser ranging facility.



School: UCLA
Mission: **ELFIN**

Research Area: Exploring the loss of relativistic electrons from the radiation belts.