Capabilities of the SmallSat Platform

E. Glenn Lightsey

Director, Satellite Design Lab

The University of Texas at Austin

Small Satellites: A Revolution in Space Science

Pasadena, California

July 16, 2012

Image: UT-Austin

Today's Workshop: Back To The Future?

- 1960's Sputnik, Vanguard, early Explorers…nano and microsatellites
- 1980's SDIO Brilliant Pebbles ("Star Wars") concept was based on nanosatellites

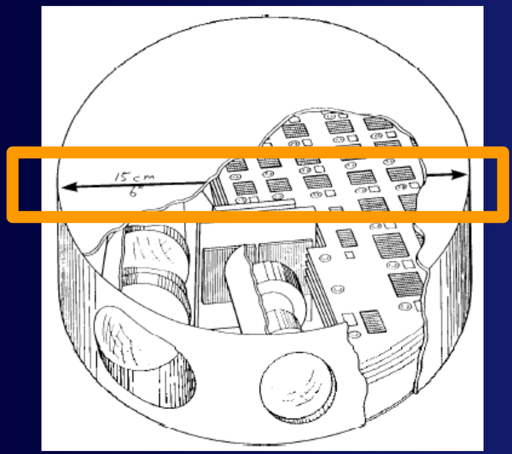


Image: Mars Observer Camera Spacecraft Concept, 15 cm diameter hockey puck, 1988

"There is a class of science and exploration missions that can be enabled by microspacecraft (i.e., infeasible with larger spacecraft). Examples include:

1) a global network of surface or atmospheric sensors on planets such as Mars, 2) measuring the spatial and temporal structure of magnetospheres about the Earth, Sun, or other regions of space, and 3) using microspacecraft as distributed arrays for either radio or optical signals."

*Ross Jones, **Microspacecraft for Space Science Workshop-Report***, California Institute of Technology/Jet Propulsion Laboratory, **1988**

A very similar meeting happened *right here* 24 years ago.

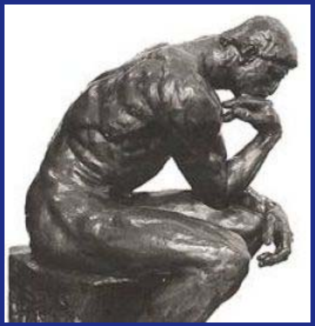
What Can We Take Away From This?

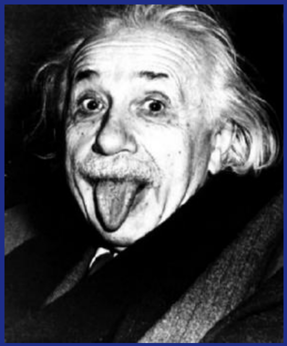
A. Great Minds Think Alike

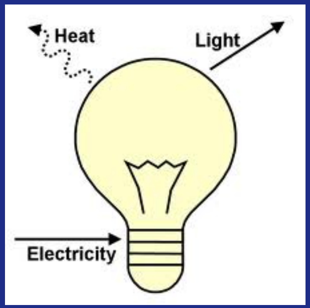
B. The Best Ideas Have Already Occurred to Someone Else

C. Basic Concepts Lead to Similar Solutions

D. Happy Hour Starts Early!







What's Changed in 24 Years

Metric	1988	2012
USA Population	244,498,982	313,906,000
Price of a Gallon of Gas	$1.08	$3.92
Most Popular Movie	Die Hard	The Avengers
Most Popular Song	Faith/George Michael	Call Me Maybe/ Carly Rae Jepsen
Number of Transistors in a Microprocessor	200,000	4,000,000,000
Value of a Share of Apple Stock	$10.36	$604.97
Total US Debt	$2,602,337,712,041	$15,500,000,000,000
NASA Adjusted Budget (2007 Dollars)	$14.45B	$16.01B
NASA Share of US Federal Budget*	0.85%	0.48%

*Public Perception of NASA Share of Federal Budget (1997): 20%

Interpretation

We Should Be Concerned

- Everything has gotten more expensive
- Purchasing power has decreased
- Space funding has decreased in both absolute and relative terms
- The manned space program is currently grounded
- We must be at least as impactful as before with less resources

But It's Not All Bad

- Advances in electronics have been staggering
- Mass production has made new powerful devices incredibly affordable
- Launch systems are more accommodating for SmallSats as secondary payloads
- Would you rather have:

Or?

A Survey of Advances in Electronics

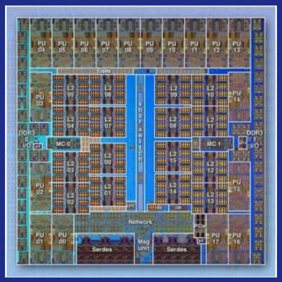
What the Consumer Electronics Industry Provides at Modest Cost

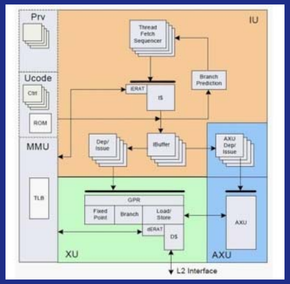
- Low Power Microprocessors
- ASICs and FPGAs
- System on a Chip (SOC) Modules
- Integrated RF Circuits
- High Speed Dynamic RAM
- High Energy Density Batteries
- High Efficiency Solar Cells
- Low Power Wireless Comms
- Small Vision Systems
- Networking Protocols
- Integrated Firmware/Software Layers
- Software Radios

And What It Doesn't Provide

- Ultra Reliable Electronics
- Radiation Hardening
- Built In Fault Tolerance
- Signal Isolation
- Synthesized Satellite Operations
- Project Level Systems Engineering

Today's SmallSats are unique and capable…
These are not your parents' SmallSats!





Images: IBM

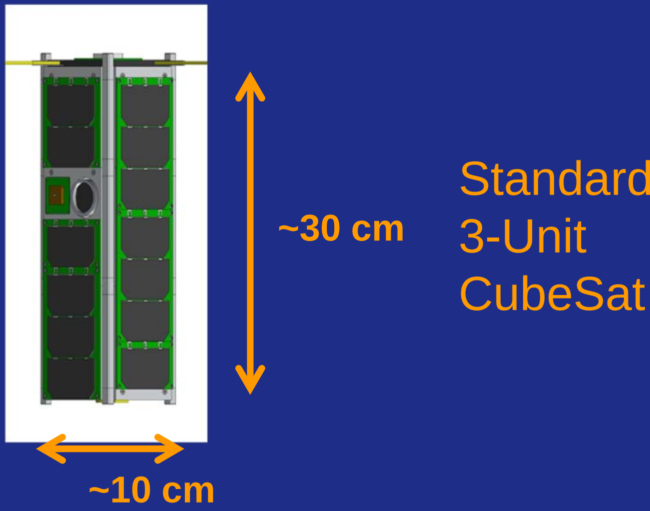
What are the Traditional Barriers to Space Exploration and Development?

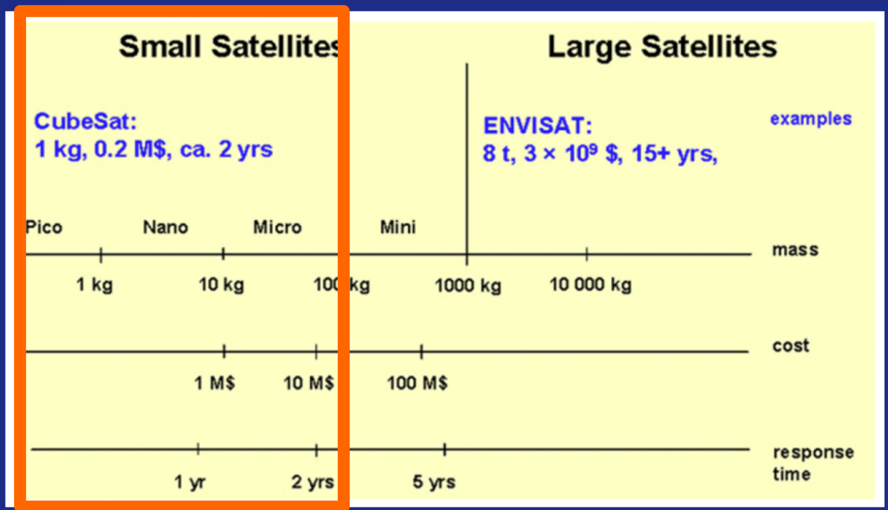
- Access
- Launch Opportunities
- Project Lifecycle Time
- Program Risk Aversion
- Cost of Equipment and Testing Scales with Size
- Cost to Orbit (~$10k/kg)
- Competition for Limited Resources

Extremely Expensive Launch Vehicle (EELV)

Small Satellites, The Enabler

- Typically Flies As Secondary Payload
- Better Access to Space
- Less Vehicle Mass
- Launch Standardization
- Shorter Time to Launch
- Lower Cost
- Ability to Take More Risk
- More Participation From Interested Communities





Small Satellites Mass-Cost-Time Relation
(from: Sandau et al., ISPRS Journal of Photogrammetry and Remote Sensing, 65, 2010)

Small Spacecraft Classification By Mass

Industry Naming Convention

Spacecraft Class	Mass Range
Microsatellite	10-100 kg
Nanosatellite*	1-10 kg
Picosatellite*	0.01-1 kg
Femtosatellite	0.001-0.01 kg

NASA Office of Chief Technologist

*Most CubeSats are Picosatellites (≤1U) or Nanosatellites (1U-6U)

Image: USAF

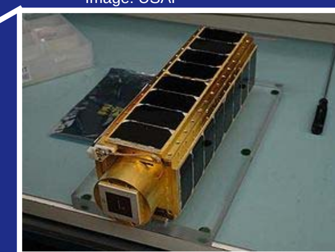


Image: NASA

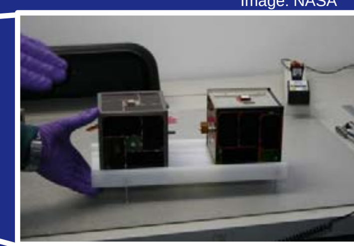


Image: UT-Austin

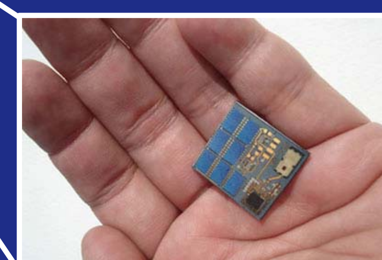
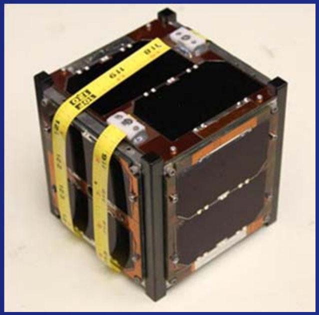
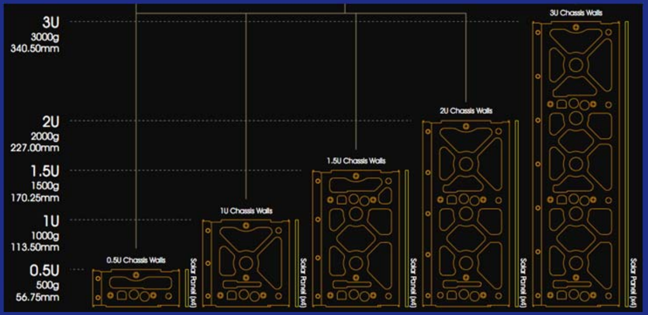


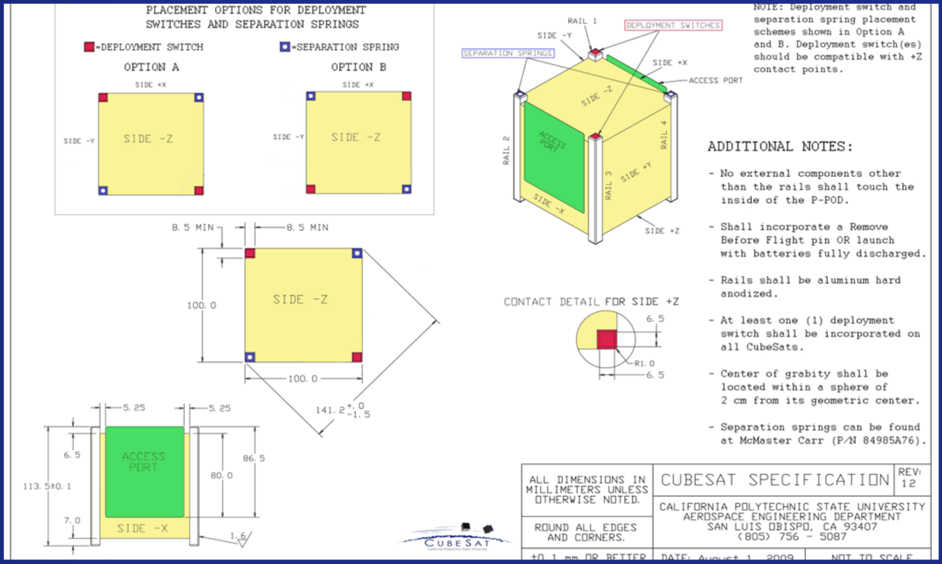
Image: Cornell Univ.

The CubeSat Standard

- Standardized platform for low-cost, frequent access to space as a secondary payload created by Twiggs (Stanford) and Puig-Suari (Cal Poly)
- Over 50 missions launched to date to Low Earth Orbit (350-850 km range)
- Longest known lifetime: 8 yrs







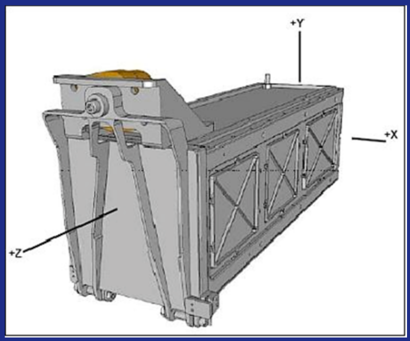
Design

- 1U: 10 cm x 10 cm x 10 cm outer dimensions, 1 kg mass
- Sizes range from 0.5U to 3U in a standard Cal Poly P-POD Deployer
- 6U and larger microsatellite deployers are being developed

Slide Credit: Matt Bennett and Andy Klesh

Secondary Payload Launch Considerations

- Ride-sharing provides space access at fractional or no cost
- Can travel into orbits that would otherwise be inaccessible (e.g. GEO, Earth escape)

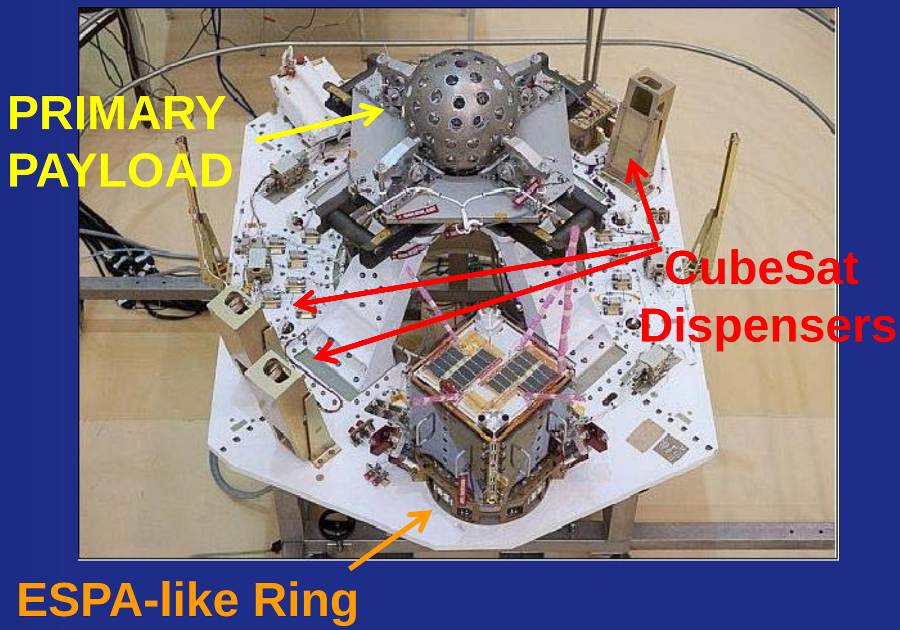


CubeSat Launcher (3U)

ESPA Ring (Microsat)

However:

- Limited flexibility to pick initial orbit or launch date
- Must conform with deployer and launch vehicle standards
- Must pose minimal risk to primary payload
- Usually require an intermediary to work with the launch provider



Historical Launches of Nanosats

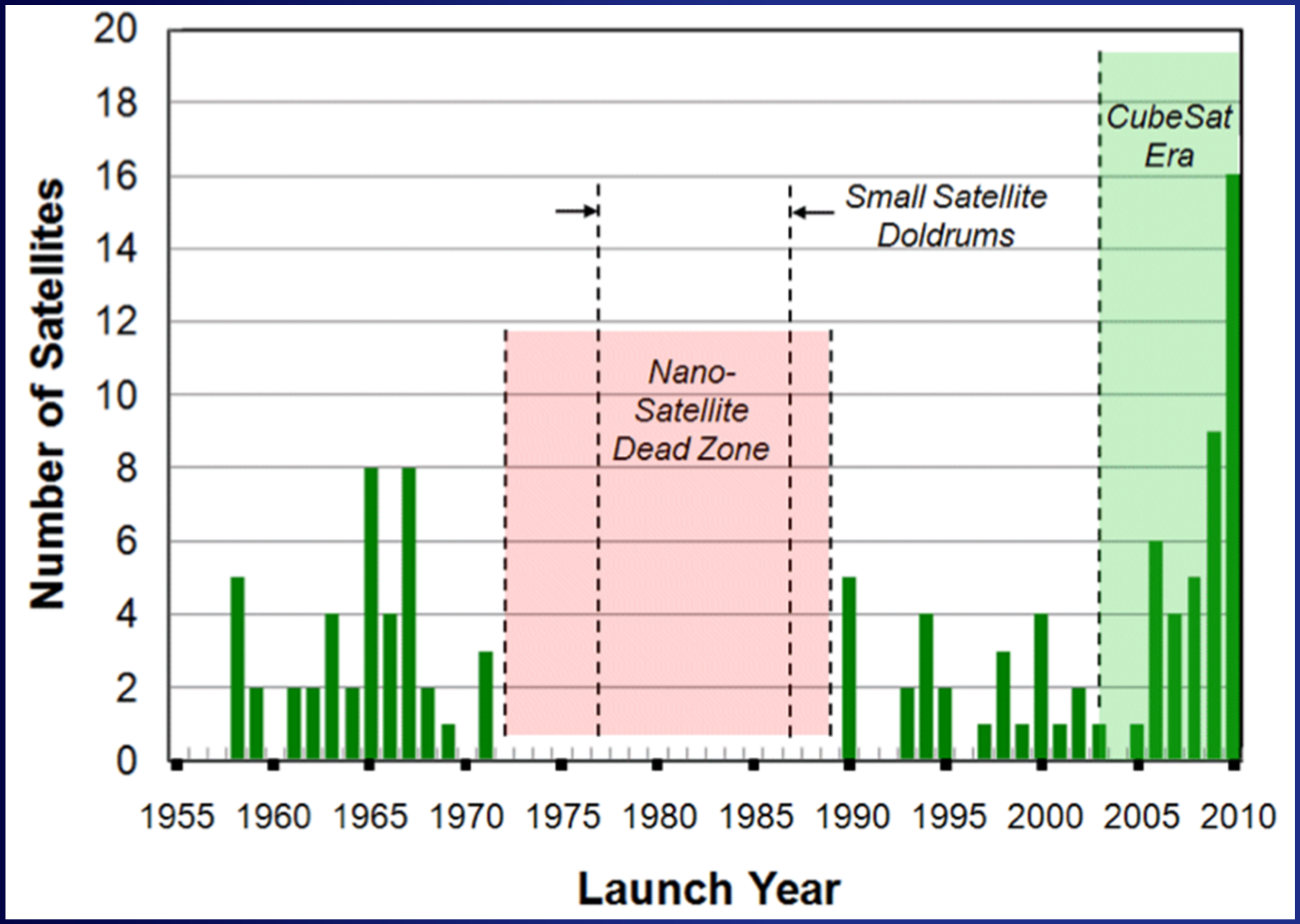


Image: Sigfried Janson, The Aerospace Corp.

6 Small Satellite Missions Past and Future

ORBCOMM

Image: ORBCOMM

SNAP-1

Image: SSTL

FASTRAC

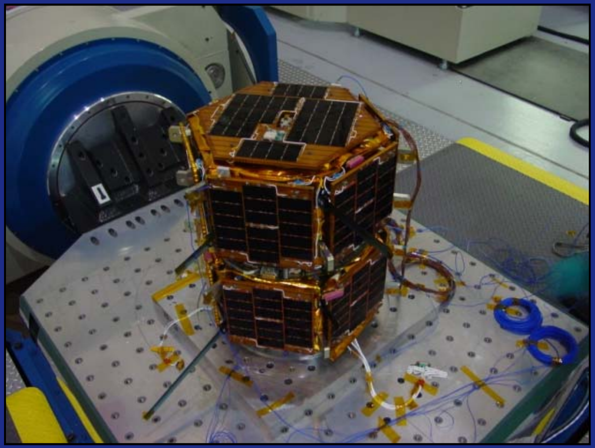


Image: UT-Austin

Nanosail-D & LightSail-1

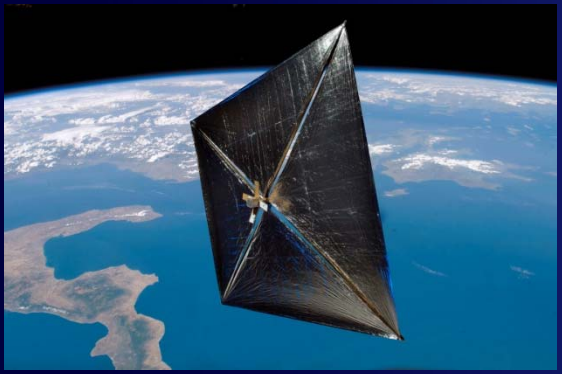


Image: NASA

QB50

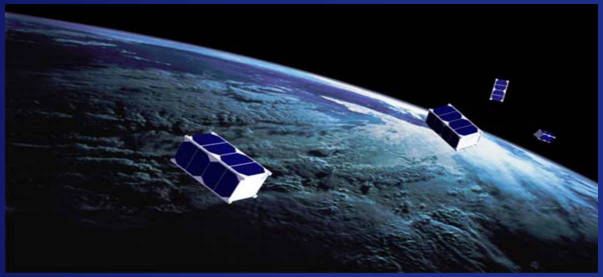


Image: Lithuania World

Phoenix

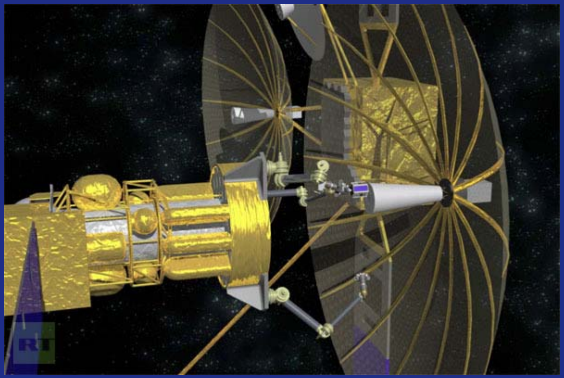


Image: DARPA

ORBCOMM's MicroStar

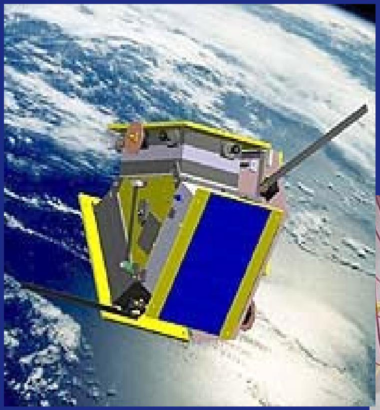
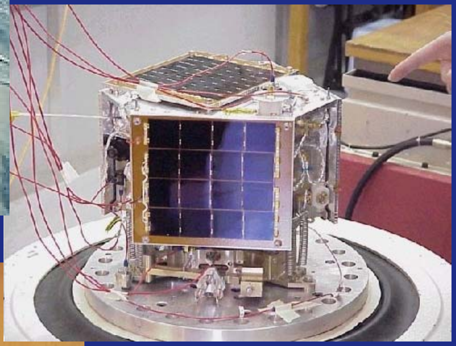
- Microsatellite (46 kg each) constellation provides commercial data service
- First satellites launched 1995, system operational since 1998
- 35 LEO satellites in six orbit planes (h=740-825 km)
- Up to 12 satellites launched from one vehicle
- Highly autonomous network
- Multi-satellite fabrication line lowered unit costs to <$5M each
- MicroStar bus used for other missions: MicroLab, BATSAT, MUBLCOM, FORMOSAT-3, TacSat-1, IBEX

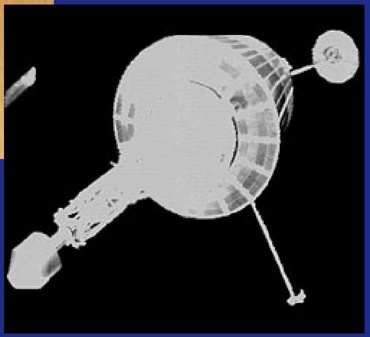
Image: Skylar Cox

Images: Orbcomm

SNAP-1

- Surrey Satellite Technology Ltd. maneuverable picosatellite (6.5 kg)
- Built with $1M internal funding in <1 year, launched 2000, h=700 km
- Payloads: VHF spread spectrum comm, UHF intersatellite comm, machine vision system (CMOS)
- 3-axis stabilized with reaction wheel and magnetorquers
- Butane thruster provided 2 m/s delta-v to reposition SNAP-1 relative to Tsinghua-1



Images: SSTL

FASTRAC

- Two Nanosatellites (20 kg each) Separate on-orbit and crosslink, sharing GPS navigation data
- Selected for Launch by 2005 University Nanosat Competition (AFRL)
- Launched on STP-S26 on November 2010
- $250K Hardware Budget For Two Flight Tested Satellites
- Estimated $2M Personnel Costs ($1M University, $1M Government)
- 18 Months Successful Post-Launch Satellite Operations And Counting

Image: USAF

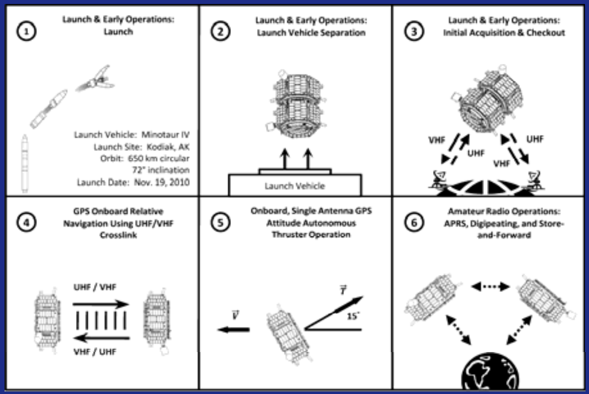


Image: UT-Austin

Image: UT-Austin

Nanosail-D and Lightsail-1

- NSD 6 months from concept to deployment
- Dimensions 3 m by 3 m
- NSD deployed from FASTSAT in January 2011 at h=650 km
- After 240 days on-orbit, NSD re-entered
- The Planetary Society’s Lightsail-1 planned launch in 2013 (part of NASA CubeSat Launch Initiative)
- LS1 will demonstrate orbit raising with CubeSat solar sail
- LS1 mission cost about $2M

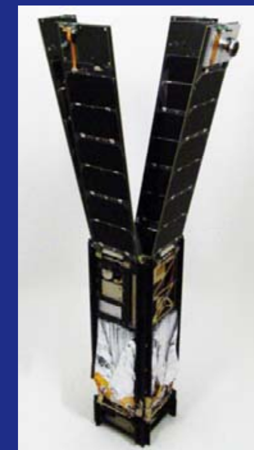


Image: Stellar Exploration, Inc.

Image: NASA

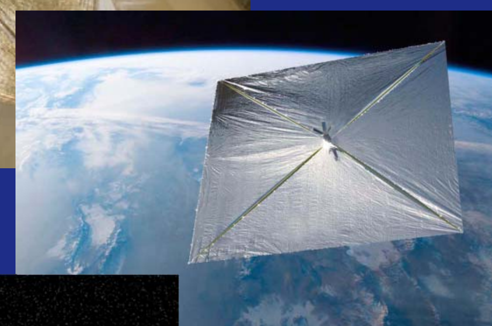
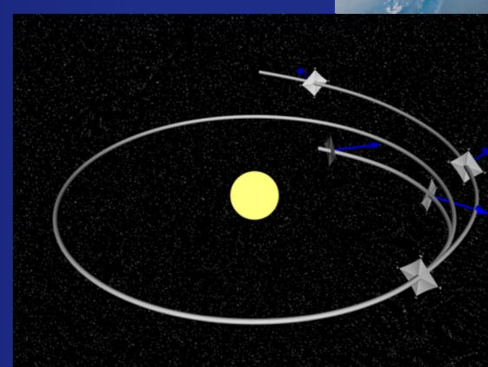


Image: Stellar Exploration, Inc.



Inner orbit: raising
Outer orbit: lowering

QB50

- An international group of 50 double CubeSats for multi-point, in-situ, long-duration measurements in the lower thermosphere and for re-entry research
- Initial altitude: h=320 km, circular orbit, i=79°
- CubeSats sequentially deployed in string of pearls from submarine launched Russian rocket Shtil 2.1
- Downlink using the Global Educational Network for Satellite Operations (GENSO)
- Planned 2015 Launch Date

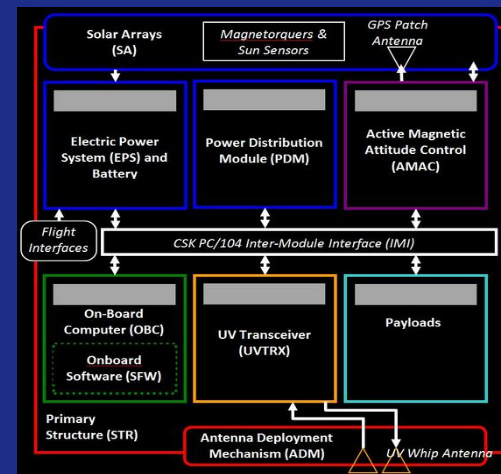


Image: ClydeSpace

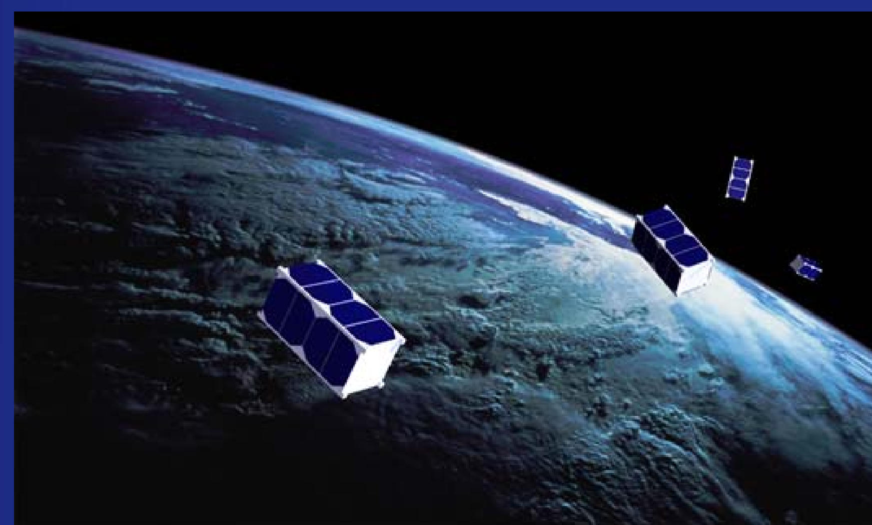
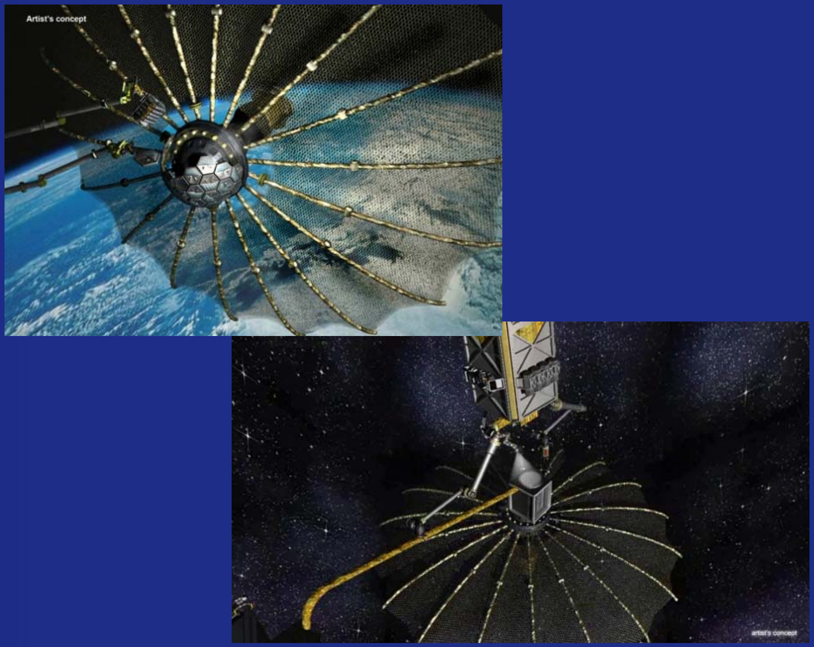


Image: Lithuania World

Phoenix

- DARPA On-orbit servicing project to re-purpose out of service GEO apertures
- Robotic tender spacecraft uses functionally specific SmallSats ("Satlets") to replace original satellite sections
- Numerous advanced technologies working together to achieve goal
- Tech demo mission planned in 2015+ time frame



Images: DARPA

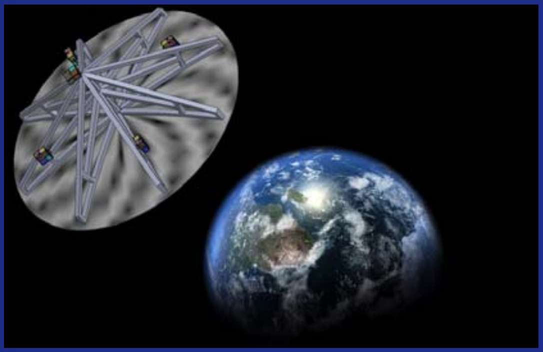


Image: UT-Austin

Other SmallSat Mission Examples

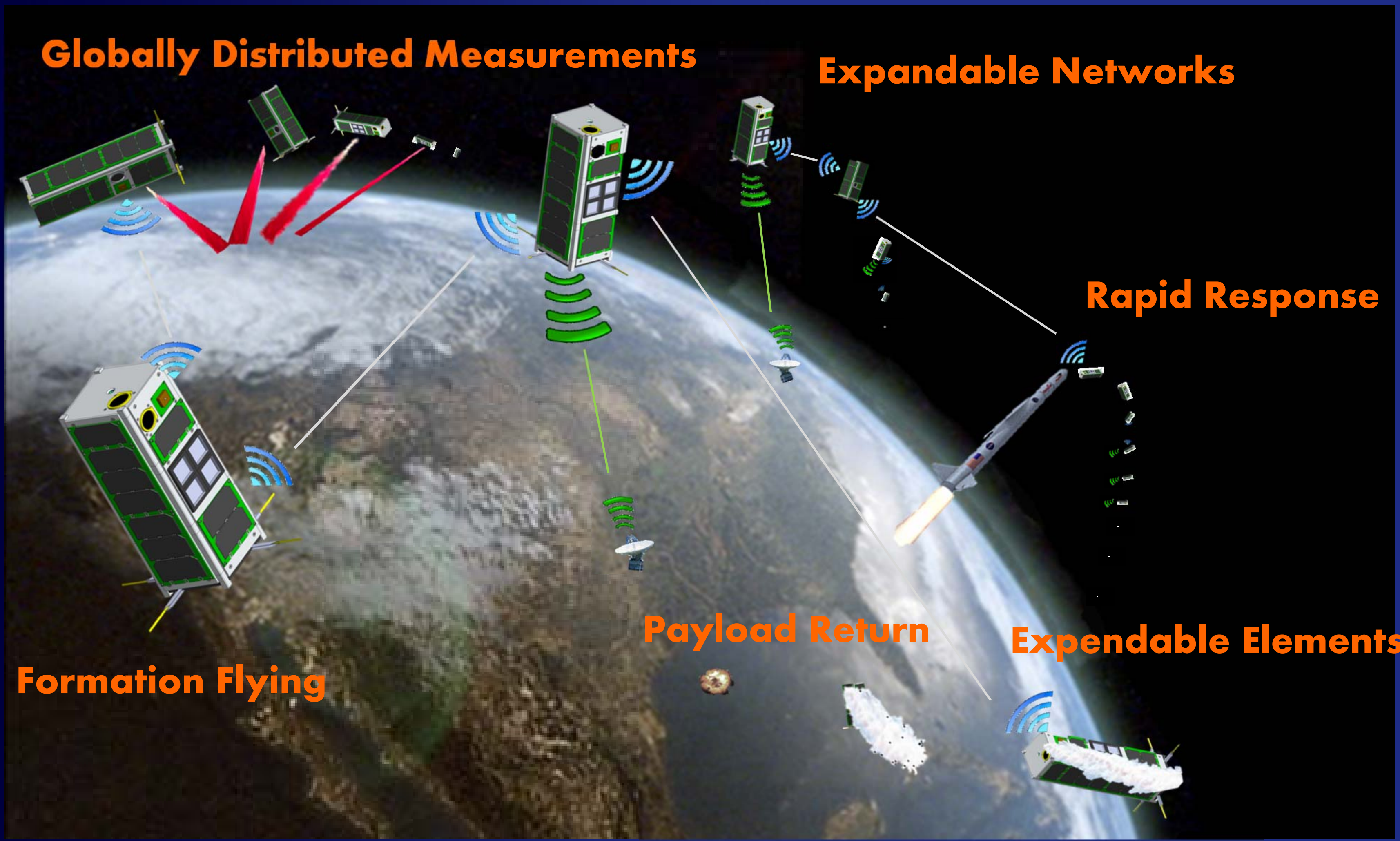
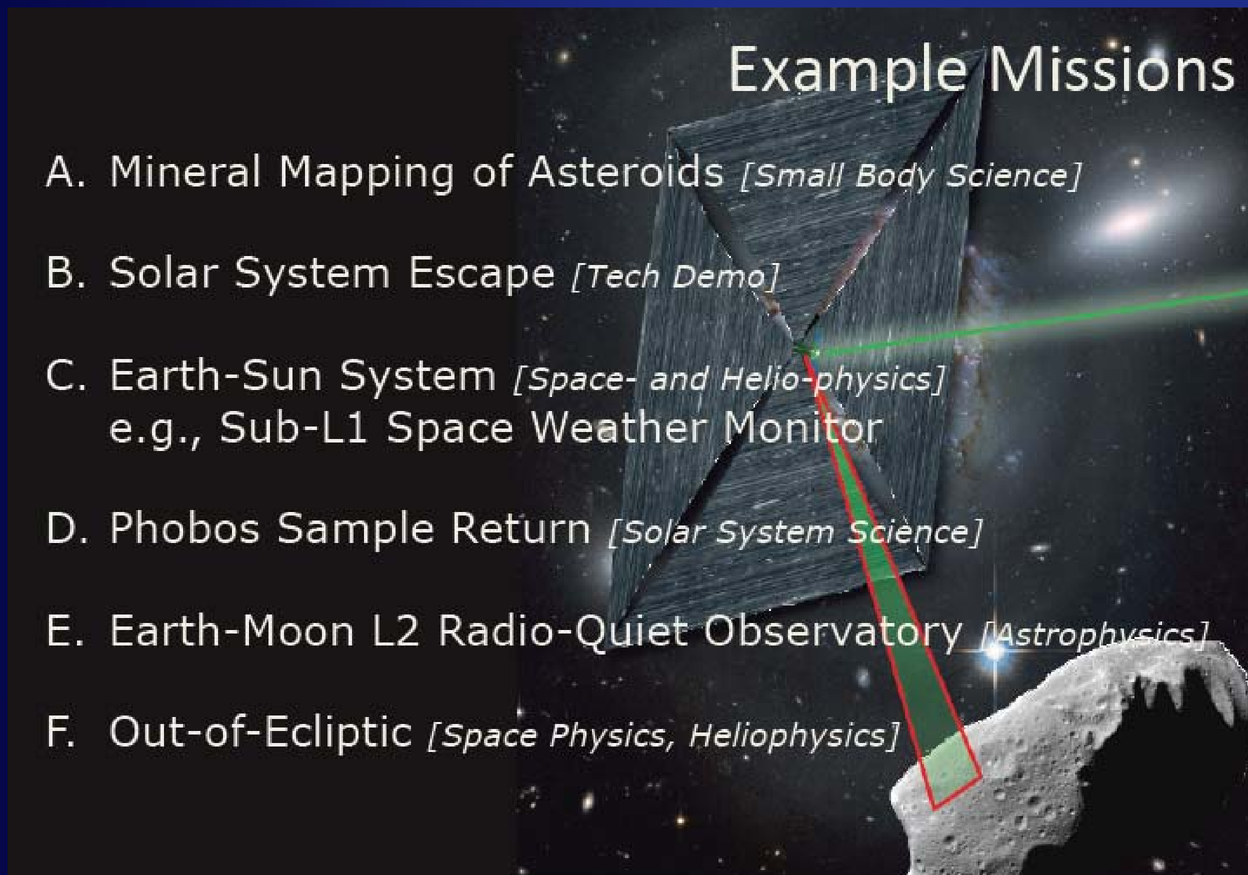


Image: UT-Austin

Interplanetary SmallSat Missions

- Funded NASA Innovative Advanced Concepts (NIAC) for Interplanetary CubeSat Missions (2012)
- 1st Interplanetary CubeSat Workshop held May 2012 at MIT



Slide Credit: Robert Staehle, NASA JPL

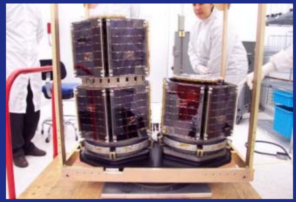
Current Programs Relevant to SmallSats (2012)

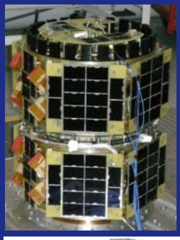
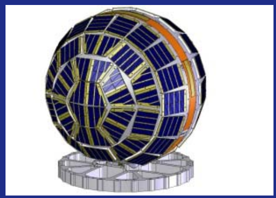
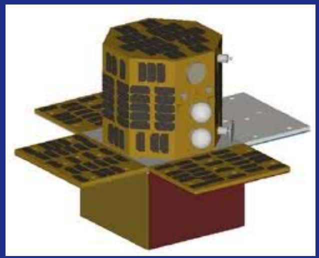
- AFOSR and AFRL: University Nanosatellite Program
- NASA: Edison Small Satellite Demo Missions
- NASA: CubeSat Launch Initiative (ELaNa)
- NSF: CubeSat-Based Science Missions for GeoSpace and Atmospheric Research

University Nanosatellite Program

- Air Force sponsored design and build competition between 10 university finalists
- First prize is a promise to launch flight unit satellite after additional development
- Seed funding is used for student education and training, university satellite bootstrapping ($55k per year)
- Program is administered by AFRL, Kirtland AFB, NM

- UNP Previous Winners:
  - NS-1 and NS-2: 3-CornerSat
    Arizona St., New Mexico St., Univ. of Colorado-Boulder
  - NS-3: FASTRAC
    Univ. of Texas-Austin
  - NS-4: CUSat
    Cornell University
  - NS-5: DANDE
    Univ. of Colorado-Boulder
  - NS-6: Oculus-ASR
    Michigan Tech
  - NS-7: Currently Ongoing (2013)



Edison Small Satellite Demos

- Flight demonstrations of small satellite technologies
- First Selections to be made in 2012
- Initial Focus Areas
  - **Demonstration of Close Proximity Operations Technologies Utilizing Small Spacecraft Systems**
  - **Demonstration of In-Space Primary Propulsion Technologies for Cubesat Systems**
  - **Demonstration of Novel Communications Systems for Small Spacecraft**
- Program is administered by NASA Ames Research Center, Moffett Field, CA

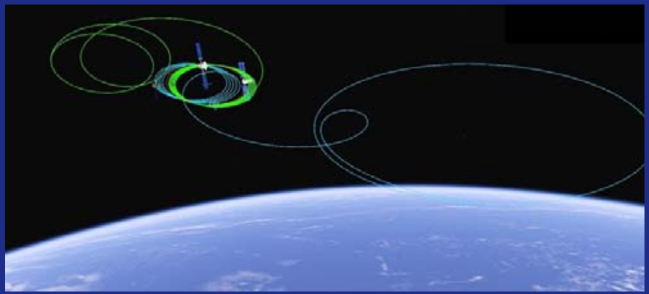


Image: Emergent Space Technologies, Inc.

Image: UT-Austin

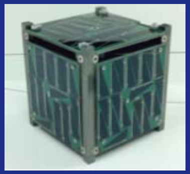
Image: NASA PhoneSat

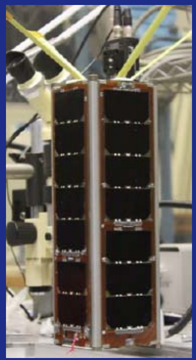
CubeSat Launch Initiative (ELaNa)

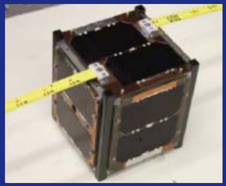
- ELaNa = Educational LAunch of Nanosatellites
- Provides opportunities for small satellite payloads to fly on rockets planned for upcoming launches
- Educational and not-for-profit organizations are eligible
- CubeSats must comply with P-POD and Launch Services Agreements
- 65 CubeSats have been selected for launch in 3 years
- Program is administered by NASA Kennedy Space Center, Cape Canaveral, FL

Missions Launched By ELaNa So Far (2012)

- Hermes, Univ. of Colorado-Boulder
- KySat-1, Kentucky Space
- Explorer-1, Montana St. University
- AubieSat-1, Auburn Univ.
- RAX, Univ. of Michigan
- M-Cubed/COVE, Univ. of Michigan/JPL
- DICE, Utah St. Univ.







Images: NASA

CubeSat-Based Science Missions for GeoSpace and Atmospheric Research

- Provides observations from space for the following focus areas:
  - Physics, chemistry, and dynamics of Earth's atmosphere
  - Dynamics of the Sun as it pertains to the Earth's atmosphere
  - Space weather processes and effects
  - Climate processes and variations
  - Natural global cycles of gases and particles in the Earth's atmosphere
- Spacecraft must fit within 3U CubeSat and comply with P-POD Standard
- Program is administered by NSF Division of Atmospheric and GeoSpace Sciences

- Recently Selected Projects
  - CubeSat-based Ground-to-Space Bistatic Radar Experiment--Radio Aurora Explorer (RAX), Univ. of Michigan at Ann Arbor
  - Dynamic Ionosphere Cubesat Experiment (DICE), Utah St. Univ.
  - Firefly--Understanding Earth's Most Powerful Natural Particle Accelerator, Siena College
  - CubeSat for Ions, Neutrals, Electron, and Magnetic Fields (CINEMA), Univ. California-Berkeley
  - Focused Investigations of Relativistic Electron Burst Intensity, Range, and Dynamics (FIREBIRD), Montana St. Univ.
  - Cubesat investigating Atmospheric Density Response to Extreme driving (CADRE), Univ. of Michigan-Ann Arbor
  - Composition Variations in the Exosphere, Thermosphere, and Topside Ionosphere (EXOCUBE), Scientific Solutions, Inc.

Some Technologies to Watch

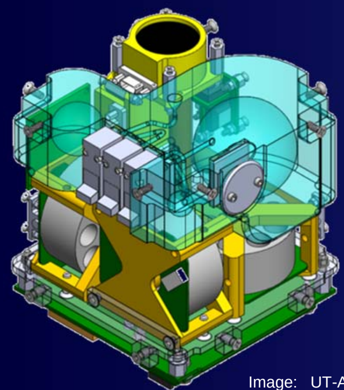
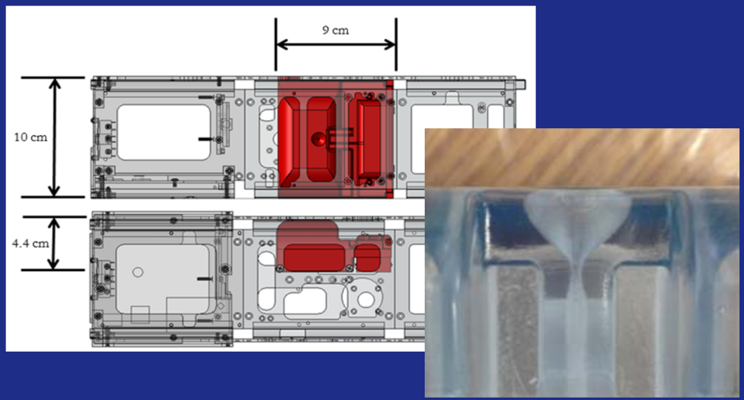


Image: UT-Austin

Integrated Guidance and Control Systems

Image: UT-Austin

Miniaturized Optical Sensors



Images: UT-Austin

Rapid Prototype Devices/Thrusters

Image: XBee

Compact & Low Power Radios

Optical Comm

Image: La Sapienza Univ. of Rome

Deployable Structures

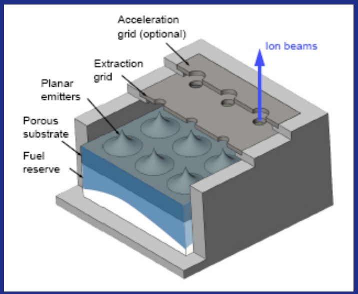


Image: MIT

Low Thrust Devices

SmallSats for Space Science-Now?

- SmallSats are not a new concept, but
  - Economic and technology factors are combining to make SmallSats popular
  - Advances in electronics and miniaturization make SmallSats more capable platforms than in the past
  - Deployer standards provide space access at more affordable prices than ever before
- Despite promise, are SmallSats a solution in search of a problem?
- We need great science ideas, engineering muscle, and programmatic leadership
- Will SmallSats bring a revolution to space science?

Image: The Aerospace Corp.

Image: NASA

The Future Belongs To Us…*carpe diem!*