Doing Science with University CubeSats

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The National Science Foundation

Committee on Achieving Science Goals with CubeSats 06/22/2015
NSF and Space

- Long tradition of utilizing space observations in research, e.g. in astronomy, astrophysics, space physics, and geosciences
- Mostly based on data provided by NASA, NOAA, and DOD.
- Recently small ventures into also providing scientific measurements from space
NSF and CubeSats

- Exploring untraditional, creative, and low-cost ways to provide space measurements for scientific research
Motivation: Science

CubeSat missions do:

- advance research in many science areas
- spur innovation, creativity and technology development
- Bring space missions within the scope of traditional NSF grants
- enhance university participation in space activities
Cubesats: Obvious Limitations

- Physical size (optics, booms, antennas)
- Power, data rate downlink
- Pointing, maneuvering
- Limited control of orbits
Important Trade-offs

- **Large missions**
  - Single satellites
  - Comprehensive measurements – Complex missions
  - Long lead-times

- **Small missions**
  - Multi-point simple measurements
  - Narrowly focused objectives
  - Fast turn-around
  - Experimental approaches
  - Dispensable & replenishable
Cubesat contributions

- Fill-in gaps in coverage
  - geographic, local time, sky-view, long-time monitoring
- Small-scale structure
  - Multi-point measurements to avoid space-time aliasing
- Interferometry & Tomography
  - Satellite constellations
- New measurements
  - Technology experiments

Motivation: Education and Workforce

CubeSat projects do:

- train the next generation of scientists and engineers in space
- offer rare full, end-to-end mission experience
- spur new excitement for science & engineering
A New NSF Program

- Program conceived 2007; first solicitation 2008
- Utilize CubeSat and P-POD technology development
- Space weather & atmospheric research and education
- 2 new projects per year
NSF Cubesat Program since 2008

- Geospace & atmospheric science and education
- 5 competitions with >80 unique missions proposed
- 12 (15) projects funded
- Grants $900,000 total cost and 3 year duration
Launch Support

- DOD STP, S26, Nov 2010, Minotaur IV, Kodiak
- NASA ELaNA, NPP, Oct 2011, Delta II, Vandenberg
- NRO/NASA ELaNA NROL-36/OutSat, Sep 2012, Atlas V, Vandenberg
- ORS, STP-3, Nov 2013, Minotaur-1, Wallops Island
- NRO/NASA ELaNA NROL-39/GEMSat, Dec 2013, Atlas V, Vandenberg
- NASA ELaNA, SMAP, Jan 2015, Delta II, Vandenberg
Mission Support at NASA Wallops Flight Facility

- Integration, testing, documentation
- Technical POC for satellite developer and launch provider
- Other technical and management support
- UHF and S-Band CubeSat Ground-station support
- As needed & less than 10% of budget
Total 2008-2015: $15.6M

CubeSat Funding FY 2008-2015

- Average (excl. ARRA) over 8 years: $1.6M
- ARRA provided 2 satellite projects and a REU site

Note: 2015 numbers are estimated
Total Funding 2008-2015: $15.6M

<table>
<thead>
<tr>
<th>FY</th>
<th>Project funding (not including ARRA)</th>
<th>ARRA funding</th>
<th>Support funding</th>
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<td><strong>Total</strong> $11,198,320</td>
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Support funding ~10%
NSF staff ~1/3 FTE

Note: 2015 numbers are estimated
Accomplishments

- Scientific value of CubeSat missions confirmed
- Creative mission ideas and successful implementations
- Scientific data & papers
- Big educational impact
- Increased recognition of cubesats as a viable alternative for space
Cubesats in LEO

- Capability already demonstrated, or will be soon for:
  - Electric and magnetic field instruments
  - Plasma density and temperature instruments
  - Neutral gas pressure gages and wind instruments
  - Mass spectrometers
  - Particle detectors (few keV to several MeV)
  - Photometers and spectrometers (near-Infrared to extreme Ultraviolet)
  - Hyper-spectral imagers
  - Gamma and X ray detectors and spectrometers
  - Radar and other advanced radio receivers
    - GNSS receivers for radio occultation
    - Multispectral microwave radiometers
Essential Elements

- Strong science and engineering collaborations
- Thorough proposal review and selection as guarantee for success
- Requirements dictated solely by launch acceptance
- Minimal prescriptions for project management (testing, review, and documentation)
- Open inter-team discussions
- Funding for students
Cubesats: Change of mindset

Powerful concepts:
- Building to a standard
- Containerized launch

New paradigm:
- Low cost
- High risk acceptance
- Broad participation:
  - high influx of innovation & widespread expertise
The Future

- Secure stable funding line at $2.5 million/ year
- Expansion to other science areas
- Larger constellations (European QB50 project)
- Cubesats everywhere: beyond LEO
- Frequency allocation &
SRI International & U. Michigan

- Ionospheric Plasma Irregularities
  - 3U cubesat
  - UHF Radar Receiver

- RAX I Launched Nov 2010
  - A few experiments; Premature power system failure

- RAX II Launched Oct 2011
  - Complete mission success
  - Operational nearly 18 months
RAX Results

- New findings on sub-meter scale auroral irregularities
  - Conducted a total of 30 experiments; recorded echoes in 4
  - Including artificial heating with HAARP

- Science outcomes
  - More than 10 scientific and engineering publications and more than 15 conference presentations
  - Data from experiments available on website

- Education outcomes
  - 36 undergraduate and 3 doctoral students
  - Alumni at leading-edge companies and gov. labs, including: Jet Propulsion Laboratory, Applied Physics Laboratory, Orbital Sciences, SpaceX, Space Systems Loral, and Department of Defense research labs
- ASTRA, Inc. & Utah St. U.
- Ionospheric Storm Enhanced Density structures
  - 2 identical 1.5U cubesats
  - Electron density; B and E fields
- Launched Oct 2011
  - Part mission success for science (no E-field boom deployment)
  - Huge technology success: demonstrated Mbits/s downlink capability
  - Operational >18 months
DICE Results

- New findings on storm enhanced density structures
  - Two-point measurements of electron density and magnetic field
  - Technology demonstration of Mbits/s download capability

Science outcomes
- More than 10 scientific and engineering publications and conference presentations
- Large dataset (> 8 GB) available on website

Education outcomes
- 6 undergraduate and 3 graduate students
- Alumni at leading-edge companies including: L-3 Communications
- U. California Berkeley & International collaborators
- Ring current dynamics
  - 3U cubesat
  - Energetic ions, electrons and neutral particles (4-20keV)
- Launched Sep 2012
  - Limited mission success; comm problems; some magnetic field data
  - Spacecraft healthy for > 18 months
- U. Colorado, Boulder
- Solar Proton Events & Radiation belt dynamics
  - 3U cubesat
  - Energetic electrons (0.5-3MeV) and protons (10-40MeV)
- Launched Sep 2012
  - Complete mission success
  - More than 2 years operation
CSSWE Results

- New findings on relativistic radiation belt electrons
  - Valuable low-altitude complement to NASA’s Van Allen Belt Probes & Barrel balloon campaign.

- Science outcomes
  - 15 peer-reviewed scientific and engineering publications
  - Full dataset available at NSSDC

- Education outcomes
  - >65 students at undergraduate, masters and doctoral level
  - Basis for 4 dissertations and 3 competitive student scholarship awards
- U. New Hampshire; Montana St. U & Aerospace Corp.
- Relativistic Electron Microbursts
  - 2 identical 1.5U cubesats
  - Energetic electrons (0.3-1MeV) with high time resolution (100ms)
- Launched Dec 2013 & Jan 2015
  - All satellites fully operational; Second pair simultaneous measurements
  - High quality data
FIREBIRD Results

- New findings on relativistic electrons and relativistic electron micro bursts
  - Energy spectrum and spatio-temporal disambiguation of microbursts down to 1.5 seconds (~10km) separation
  - Valuable complement to NASA’s Van Allen Belt Probes

- Science outcomes
  - Many scientific and engineering publications and conference presentations in preparation
  - Still collecting data

- Education outcomes
  - More than 18 undergraduate and graduate students
  - Alumni at leading-edge companies and institutions including: Northrup Grumman Corp, Tyvak, Aerospace Corp, Stanford University
- NASA Goddard Space Flight Center & Siena College
- Terrestrial Gamma Ray Flashes and Lightning
  - 3U cubesat
  - Gamma Rays (to 20MeV); VLF radio and optical
- Launched Nov 2013
  - 2 months to first contact
  - Data collection and analysis ongoing
Firefly Results

- New findings on lightning physics and electron acceleration in Terrestrial Gamma Ray Flashes
  - To date, Firefly has captured over 60 science "snapshots" of high resolution measurements of lightning and gamma ray activity

- Science outcomes
  - Validation and analysis of candidate events still ongoing
  - Data collection still ongoing
  - 10 scientific and engineering publications and presentations

- Education outcomes
  - 30 undergraduate and 6 high school students
  - Internships at NASA GSFC
- Scientific Solutions, Inc; CalPoly; NASA Goddard; U. Wisconsin & U. Illinois

- Composition of the upper atmosphere
  - 3U cubesat
  - Miniature mass spectrometer; global density of H, He, and O and ions

- Launched Jan 2015
ExoCube Results

- Still in commissioning phase
  - Weak radio signal: antenna didn’t deploy
  - Successful comm with 150 foot dish at SRI: solutions at CalPoly and Wallops being worked

- Science outcomes
  - First-light measurements: Successful demonstration of the mass spectrometer instrument

- Education outcomes
  - More than 40 undergraduate and graduate students

![Graph](https://example.com/graph.png)

- EXOCUBE INMS first data
- TOF vs sqrt(atomic mass)
▪ U. Michigan & Naval Research Lab

▪ Thermosphere dynamics
  - 3U cubesat
  - Miniature mass spectrometer; density, temperature, winds and composition of neutrals and ions

▪ Launch Early 2016
Virginia Tech; U. Illinois; Aerospace Corp. & NWRA, Inc.

- Atmospheric gravity waves
  - 6U cubesat
  - In-situ and remote sensing; plasma and neutral temperature and density; Airglow \( \sim \)90km

- Project Started May 2013
  - Expected launch early 2016
- Utah St. U. & & HISS (U. Maryland Eastern Shore)
- Neutral temperature profiles 90-140km
  - 3U Boeing Colony cubesat provided by NRO
  - High resolution, hyper-spectral imaging spectrometer; Daytime airglow O2 760-770nm
- Project Started Sep 2013
- UCLA
- Pitch angle distribution of relativistic electrons and ions
  - 3U cubesat; spinning @20rpm
  - Full angular distribution of electrons (50keV-5MeV) and ions (50-300keV); Magnetic field

Project Started August 2014
- Jointly funded with NASA
- Draper Lab; U. Michigan; UC Boulder; Stanford U.; U. del Turabo

- Providing 4 Cubesats to the European-led QB50 project
  - In-situ measurements of the lower thermosphere 100-320km
  - Atlantis, Columbia, Challenger, Discovery
  - 2 Ion-Neutral-Mass-Spectrometers & 2 AO and O2 Sensors (FIPEX)
  - High resolution, hyper-spectral imaging spectrometer; Daytime airglow O2 760-770nm

- Project Started July 2014