Imagine the Future:

With Cubesats

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Atmospheric and Geospace Science Division
The National Science Foundation

GSAW Workshop 2014

The National Science Foundation

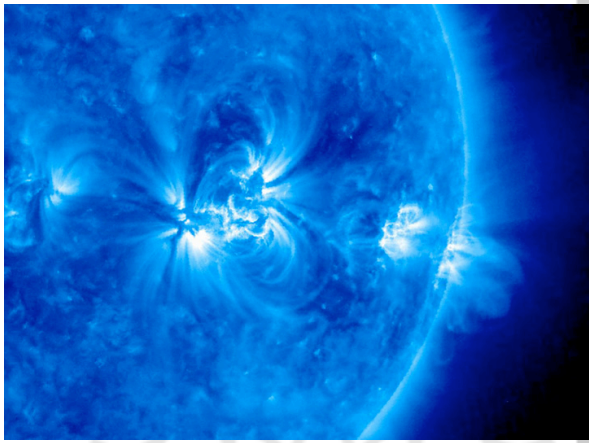
- **Independent Agency of the Federal Government of the United States since 1950**
- **Sponsors scientific research in most fields of science and engineering**

✗ operates no laboratories

✗ does not conduct in-house research

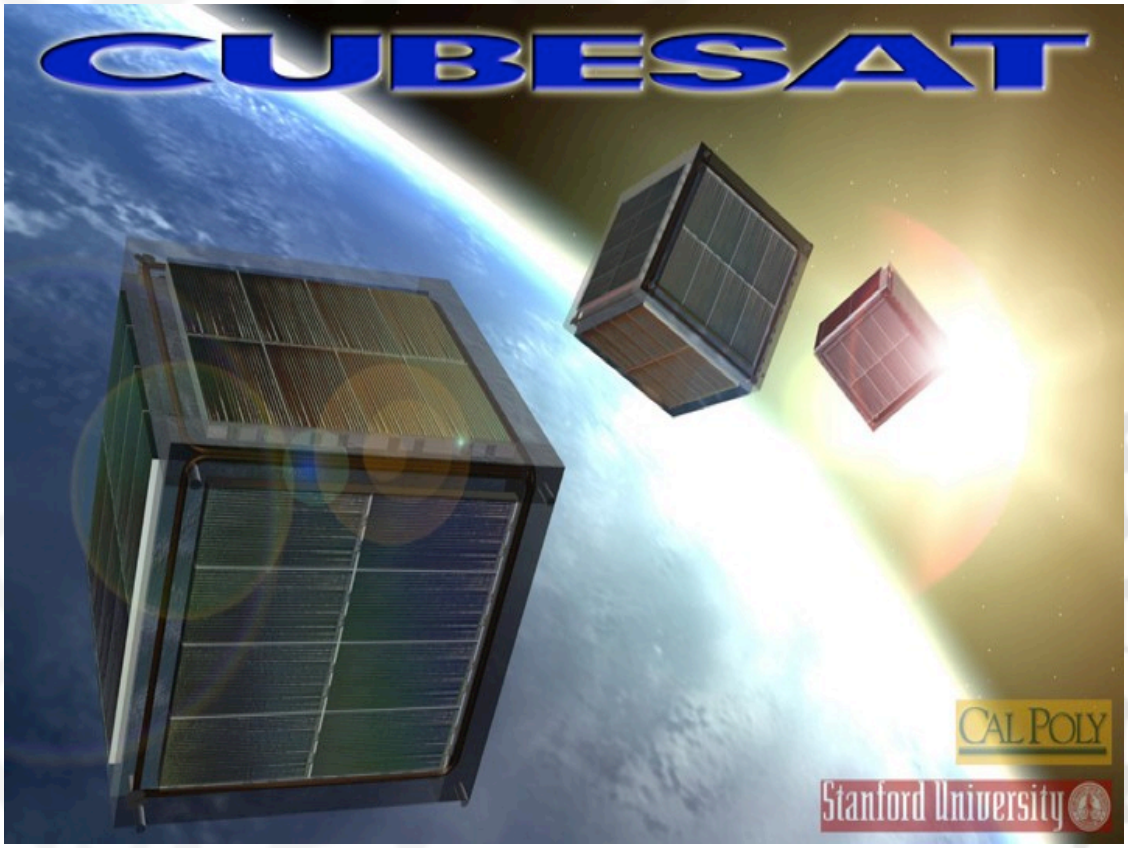
NSF and Space

- **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**

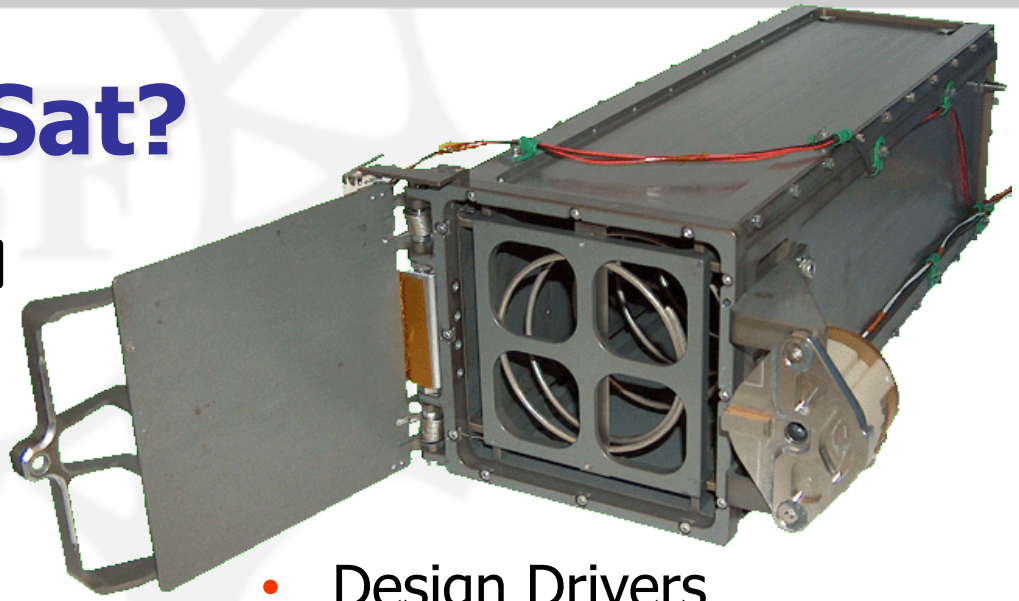


NSF and Cubesats

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

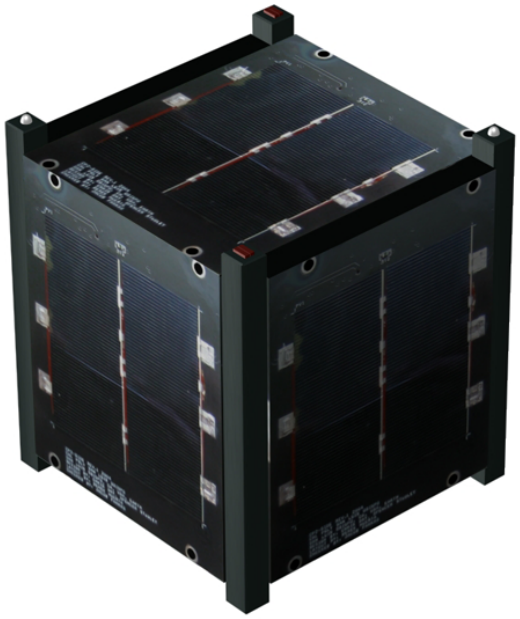


What is a CubeSat?

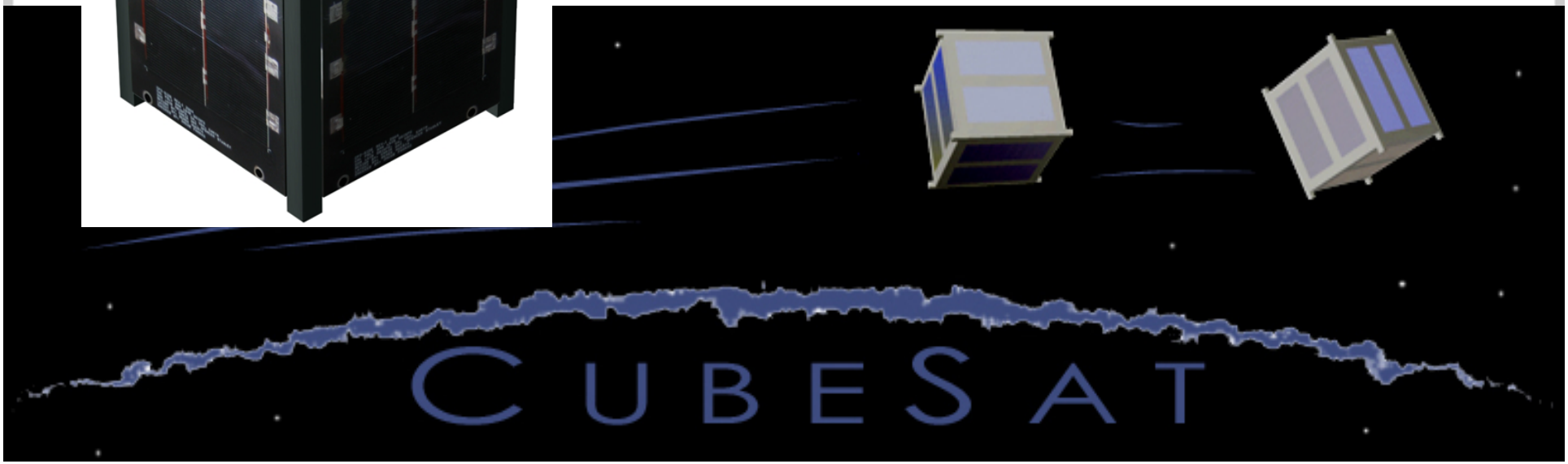


A pico-satellite Standard

1999 by Puig-Suari, CalPoly and Twiggs, Stanford

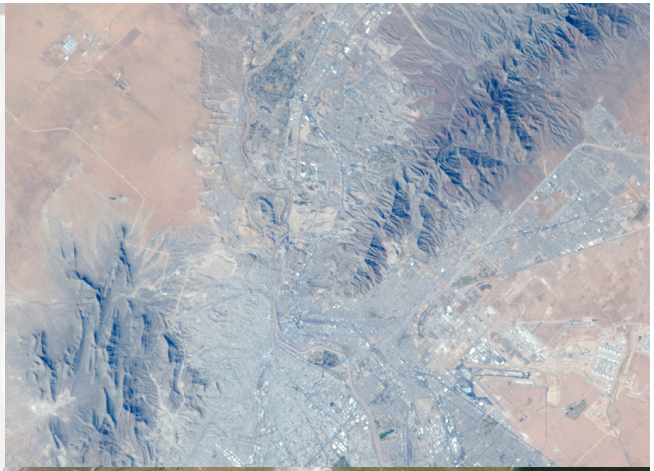


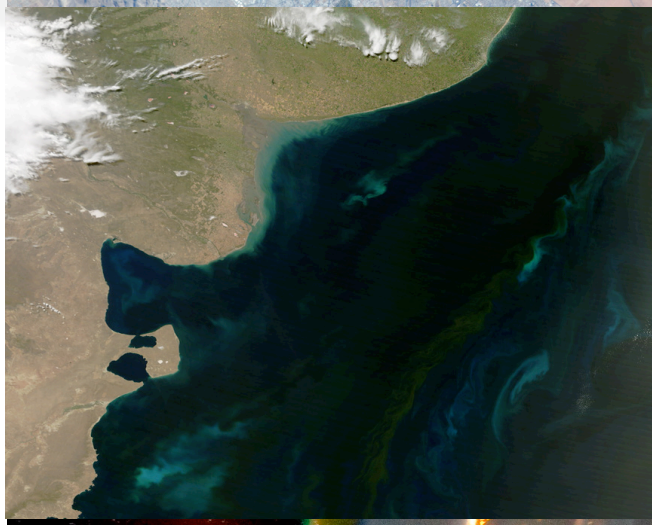
- Design Drivers
  - Simple and low-cost, but safe
  - Available COTs components
  - P-POD deployer system

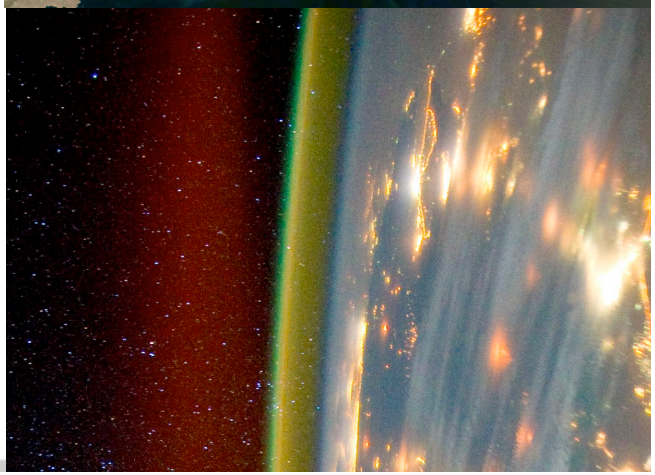


Cubesat Science

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





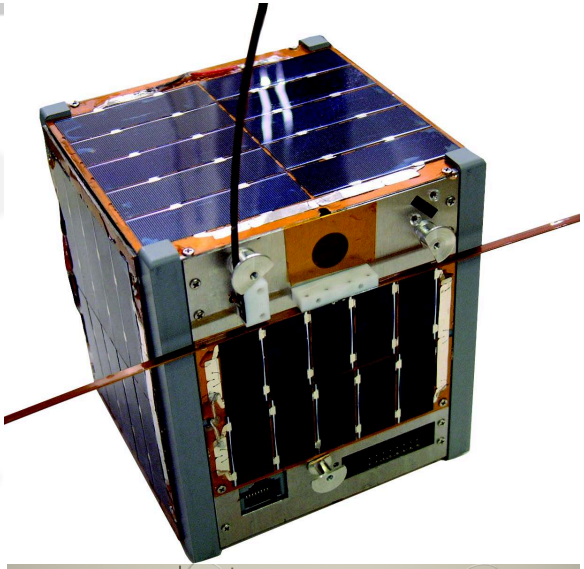


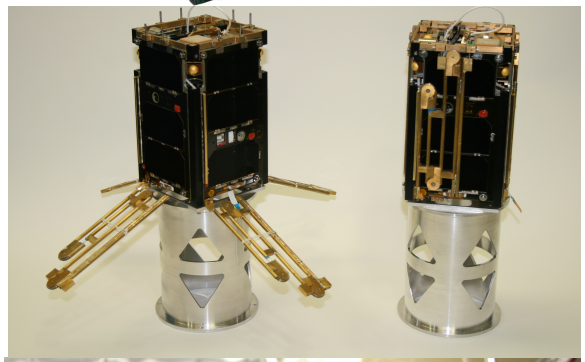
Education and Workforce

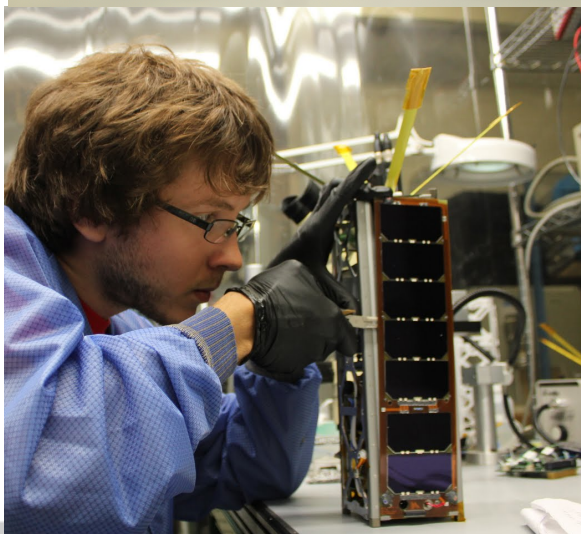
- train the next generation of scientists and engineers in space
- full, end-to-end mission experience
- spur new excitement for science & engineering

New NSF Cubesat Program 2008

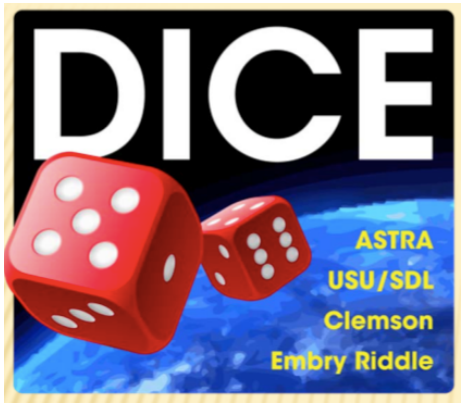
- Geospace & atmospheric science and education
- >60 unique missions proposed
- 10 projects funded
- 2 new projects per year
- Grants $900,000 total cost and 3 year duration







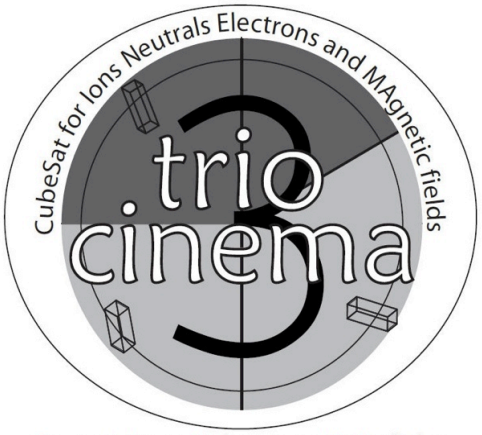

RAX 2
SRI INTERNATIONAL
U MICHIGAN
VAFB
DELTA II
NSF
ELANA-3
NPP
NASA
Scientia
Ex cubus

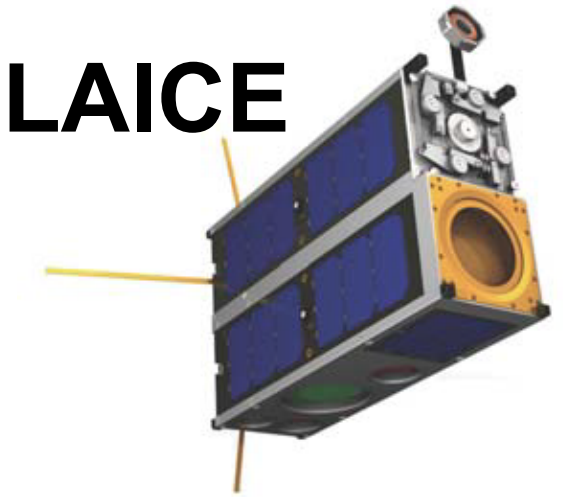

DICE
ASTRA
USU/SDL
Clemson
Embry Riddle

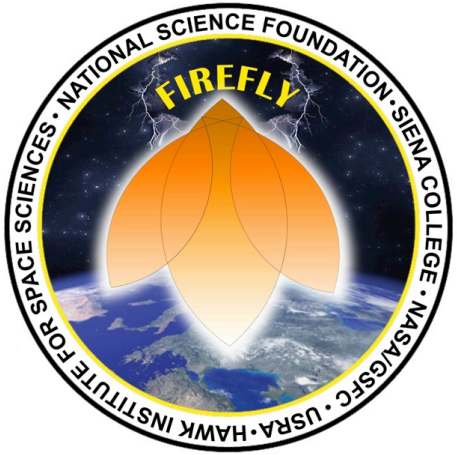

CADRE


ExoCube


CSSWE
Colorado Student Space
Weather Experiment

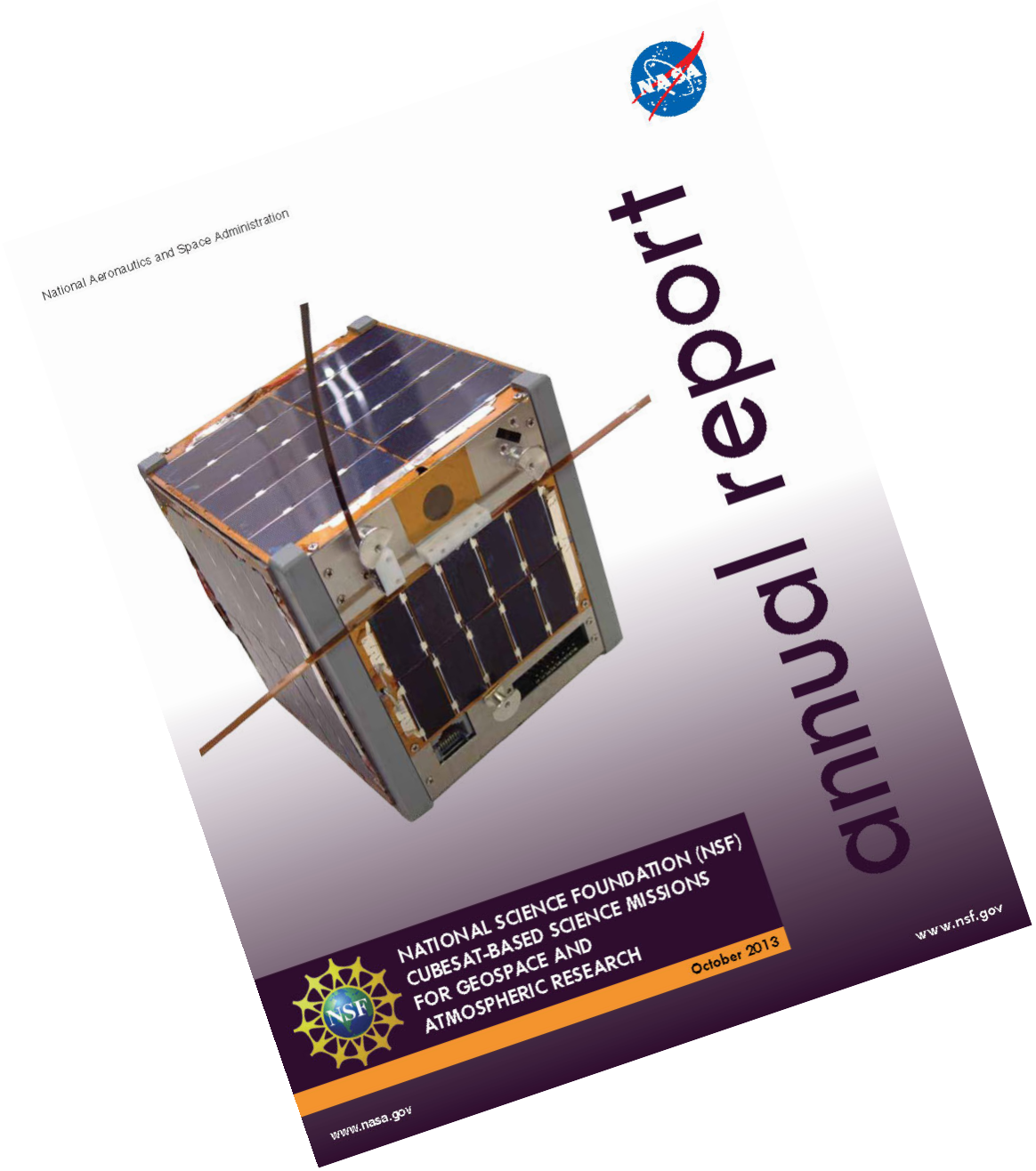

CubeSat for Ions Neutrals Electrons and MAgnetic fields
trio
cinema
3


LAICE


FIREFLY
NATIONAL SCIENCE FOUNDATION
SIENA COLLEGE
NASA/GSFC
USRA
HAWK
INSTITUTE FOR SPACE SCIENCES


FIREBIRD
Focused Investigations of
Relativistic Electron Burst Intensity,
Range, and Dynamics
University of New Hampshire
Montana State University
Los Alamos National Laboratory
The Aerospace Corporation


OPAL



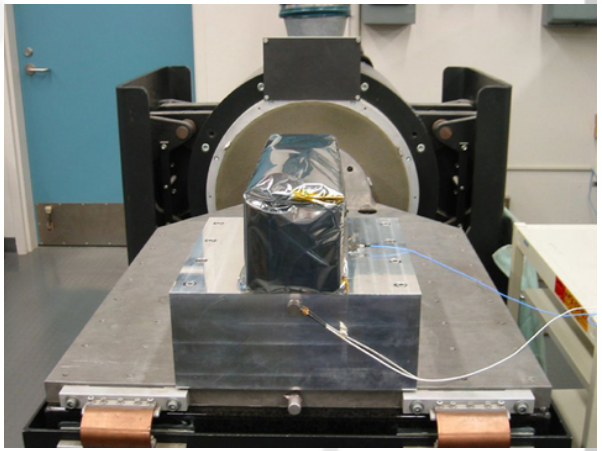
http://www.nsf.gov/geo/ags/uars/cubesat/nsf-nasa-annual-report-cubesat-2013.pdf

Launch Support

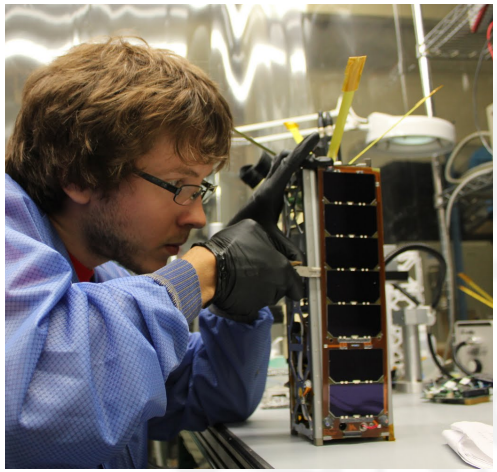
- **DOD STP, S26, Nov 2010, Minotaur IV, Kodiak**
- **NASA ELaNa, NPP, Oct 2011, Delta II, Vandenberg**
- **NRO/NASA ELaNa NROL-36/ OutSat, Sep 2012, Atlas V, Vandenberg**
- **ORS, STP-3, Nov 2013, Minotaur-1, Wallops Island**
- **NRO/NASA ELaNa NROL-39/ GEMSat, Dec 2013, Atlas V, Vandenberg**

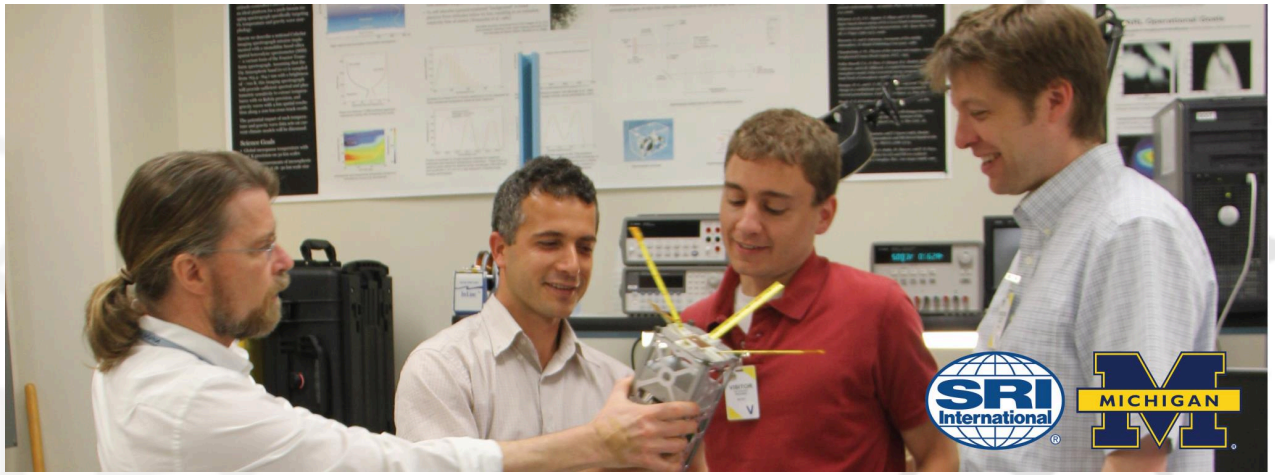
Mission Support at NASA Wallops Flight Facility

- **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**

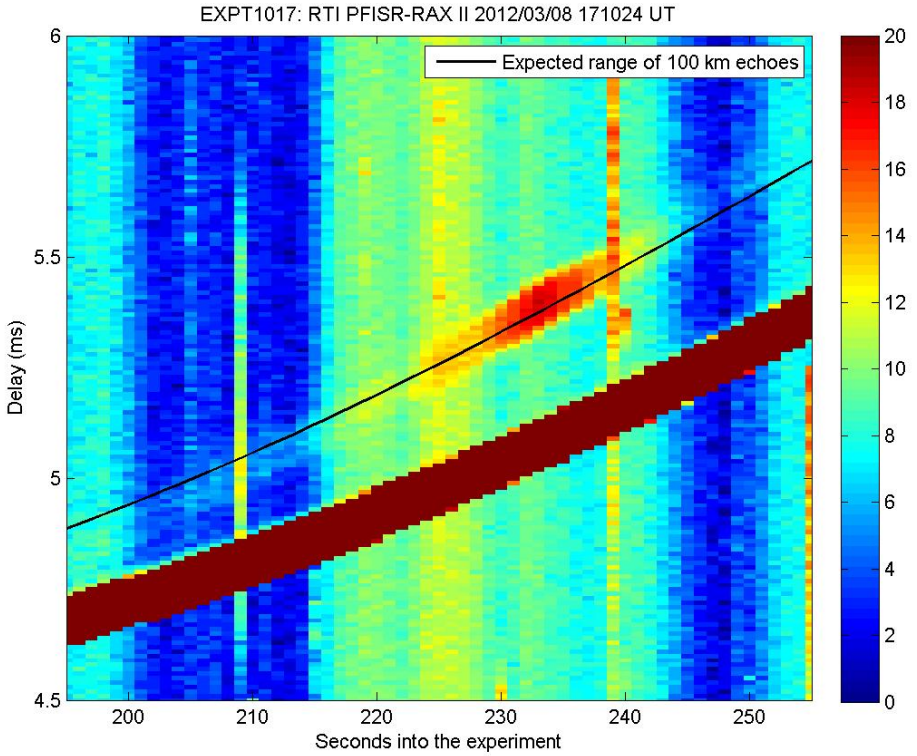


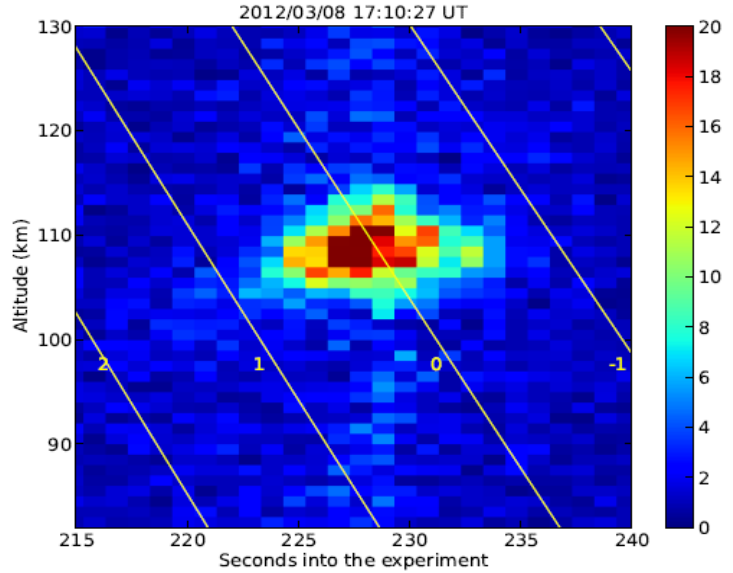
- **SRI International & U. Michigan**
- **Ionospheric Plasma Irregularities**
  - **3U cubesat**
  - **UHF Radar Receiver**
- **RAX I Launched Nov 2010**
  - **A few experiments; Premature power system failure**
- **RAX II Launched Oct 2011**
  - **Complete mission success**
  - **Operational nearly 18 months**

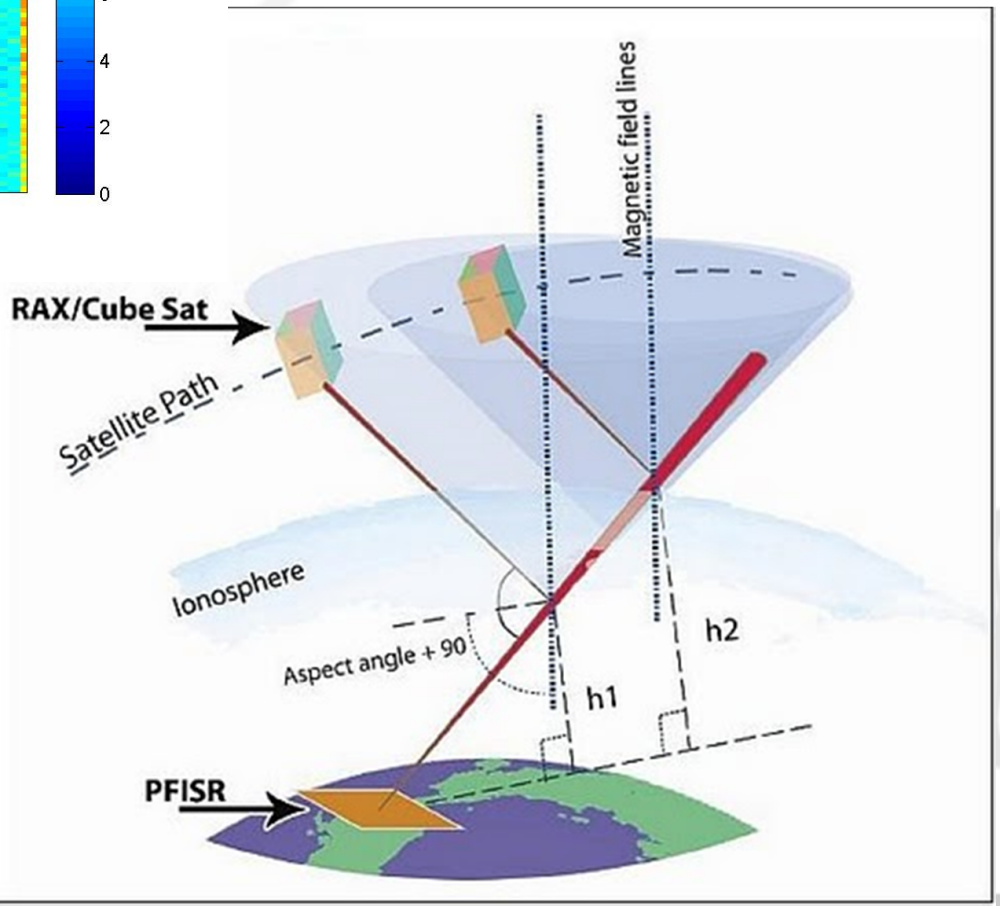




RAX observes auroral turbulence



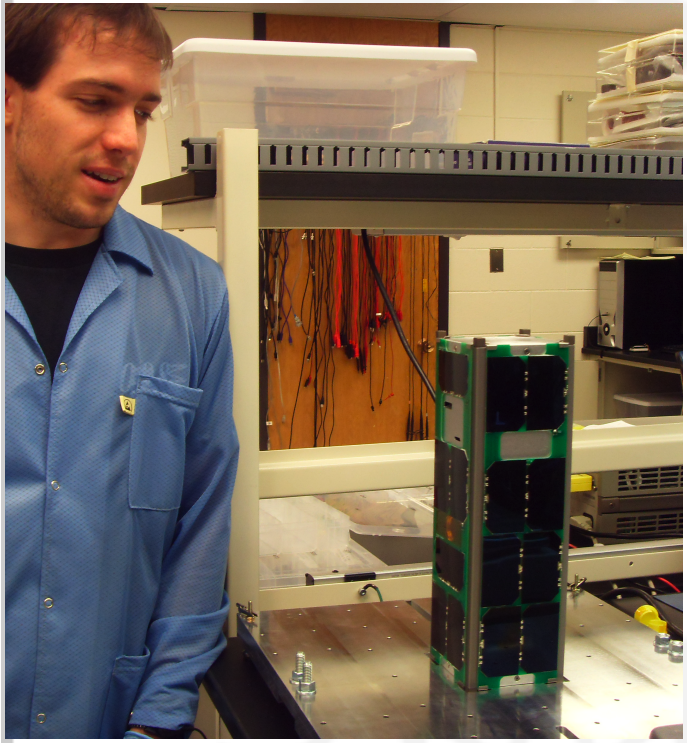


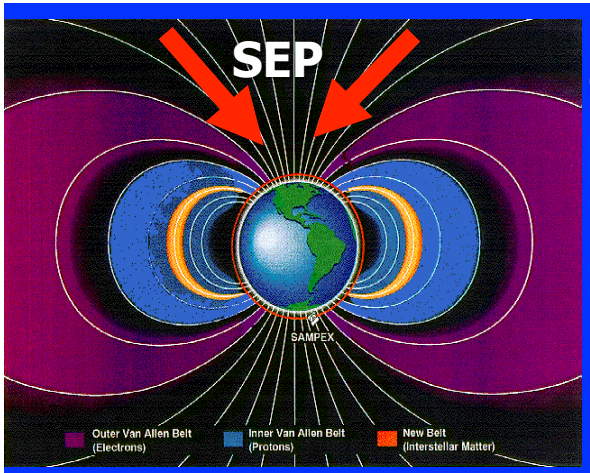


CSSWE

Colorado Student Space Weather Experiment

- 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
  - still operational (17 months)

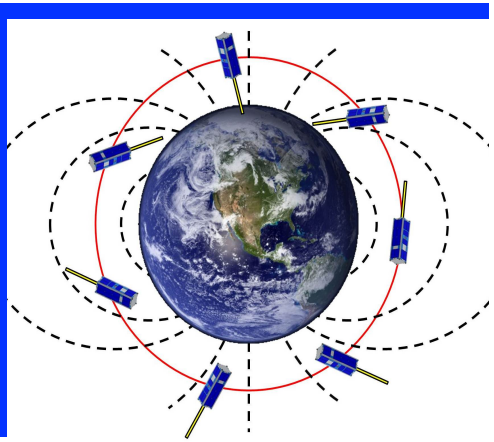




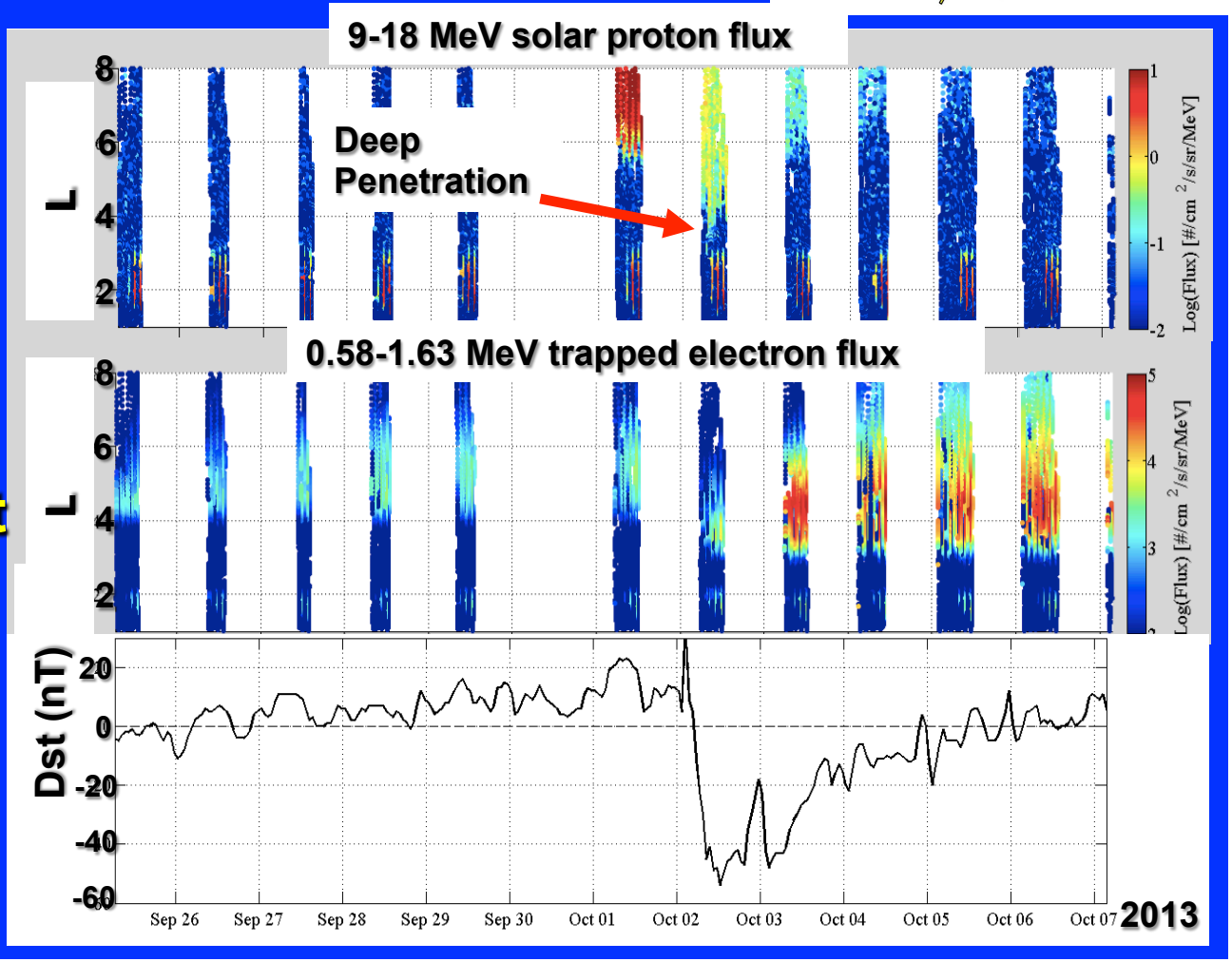
CubeSat: Colorado Student Space Weather Experiment (CSSWE)

Launched on 0913/12, still in operation

Orbit: ~480 km x 780 km, inclination 65^0



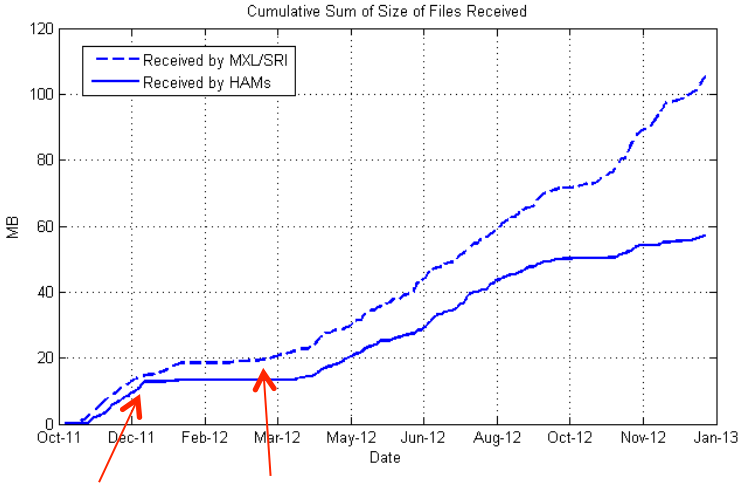
Clear separation of species during a solar energetic particle (SEP) event



AstroDev Li-1 (9600 bps radio)
UHF Amateur band
Astronautical Development, LLC.

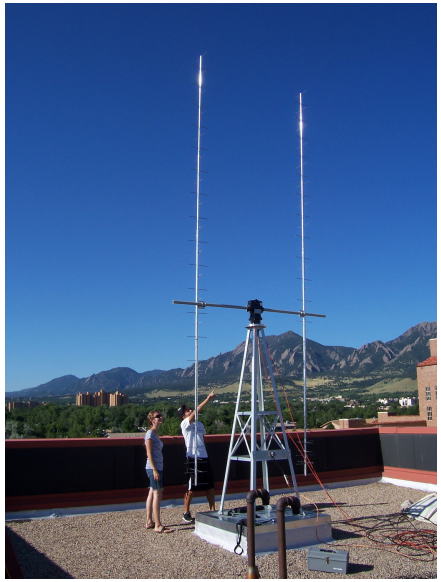
RAX Data

Data downloads

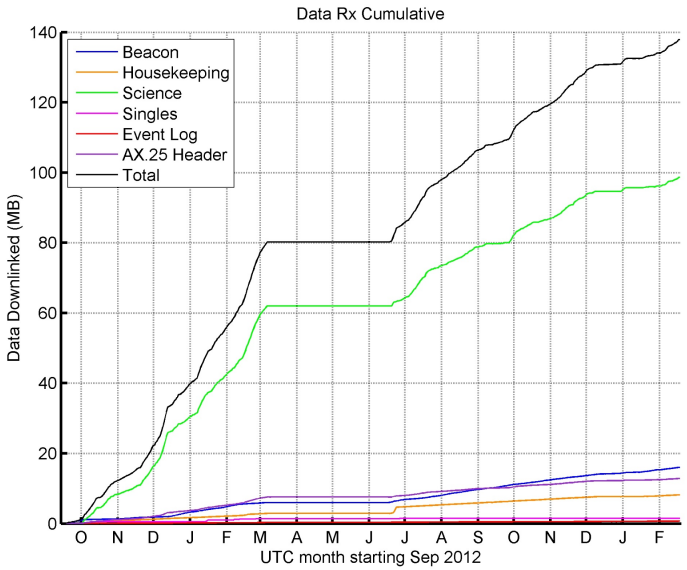


These files are primarily science data, some housekeeping data as well.

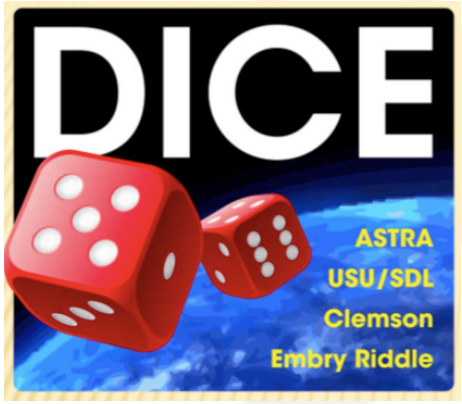
162.5 MB total
105.4 MB via Umich/SRI GS
57.1 MB via amateur community



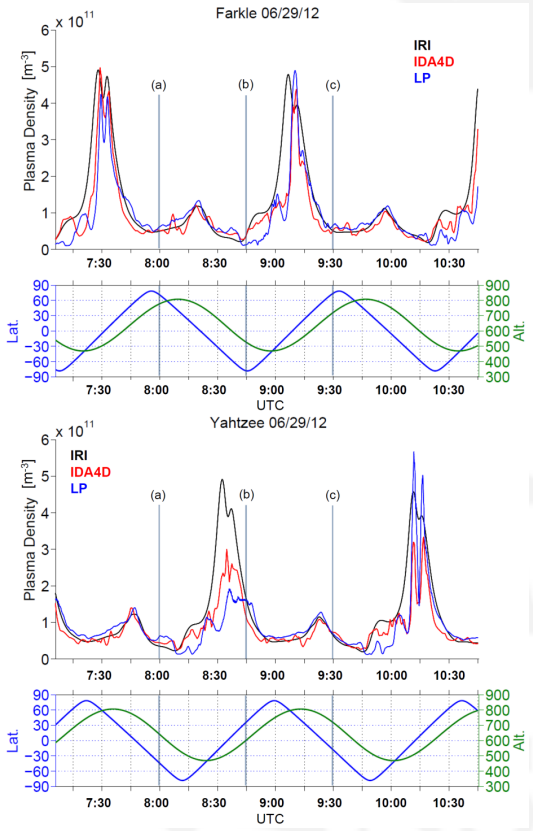
CSSWE Data



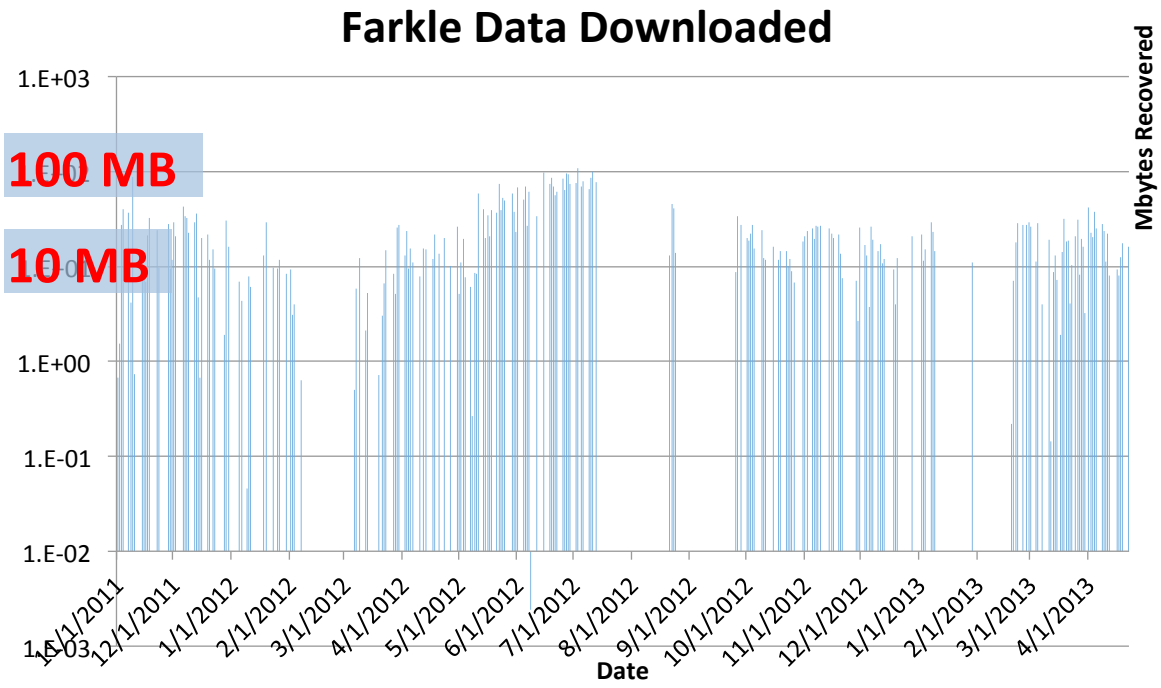
140 MB total

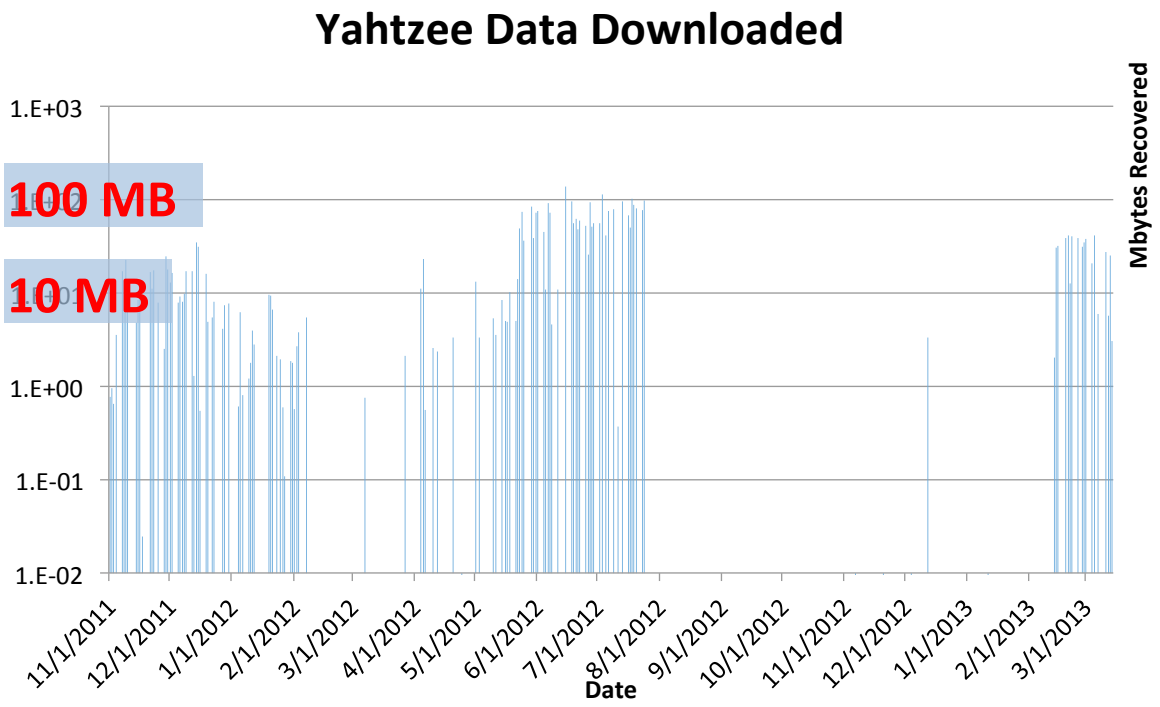


- **ASTRA, Inc. & Utah St. U.**
- **Ionospheric Storm Enhanced Density structures**
  - ❑ **2 identical 1.5U cubesats**
  - ❑ **Electron density; B and E fields**
- **Launched Oct 2011**
  - ❑ **Part mission success for science (no E-field boom deployment)**
  - ❑ **Huge technology success: demonstrated Mbits/s downlink capability**
  - ❑ **Operational >18 months**



DICE Data





L3 Communications CadetU radio
UHF 460-470MHz Gov band

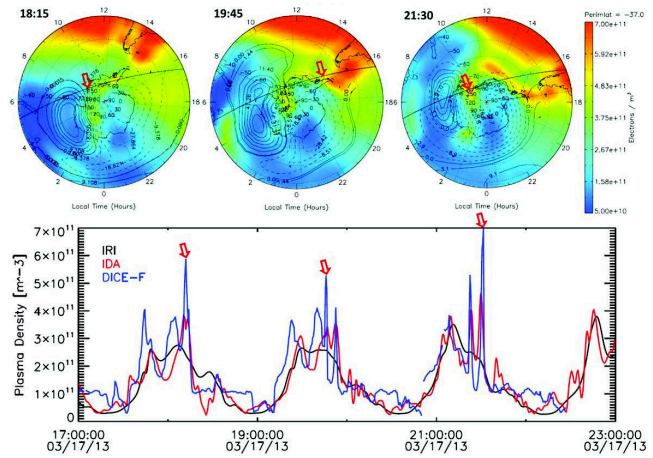
Ground station
18m dish at
NASA Wallops

Science data recovered:
Farkle 5.1 GB
Yahtzee 3.3 GB

26 TB of raw I/Q samples collected and stored

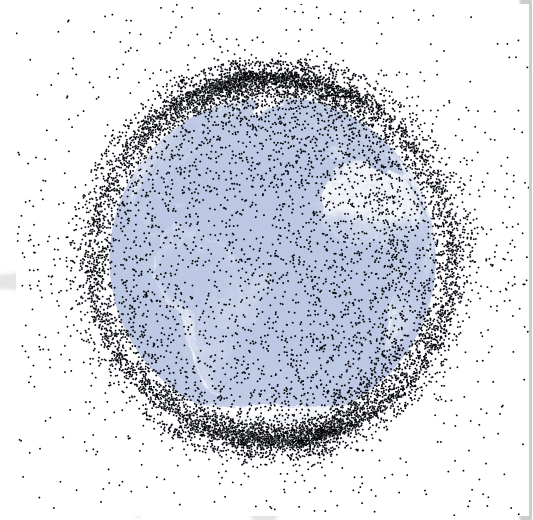
Accomplishments

- **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**



The Future

- Expansion to other science areas
- Larger constellations (European QB50 project)
- Cubesats everywhere: beyond LEO
- Frequency allocation & space debris concerns



Cubesats: Obvious Limitations

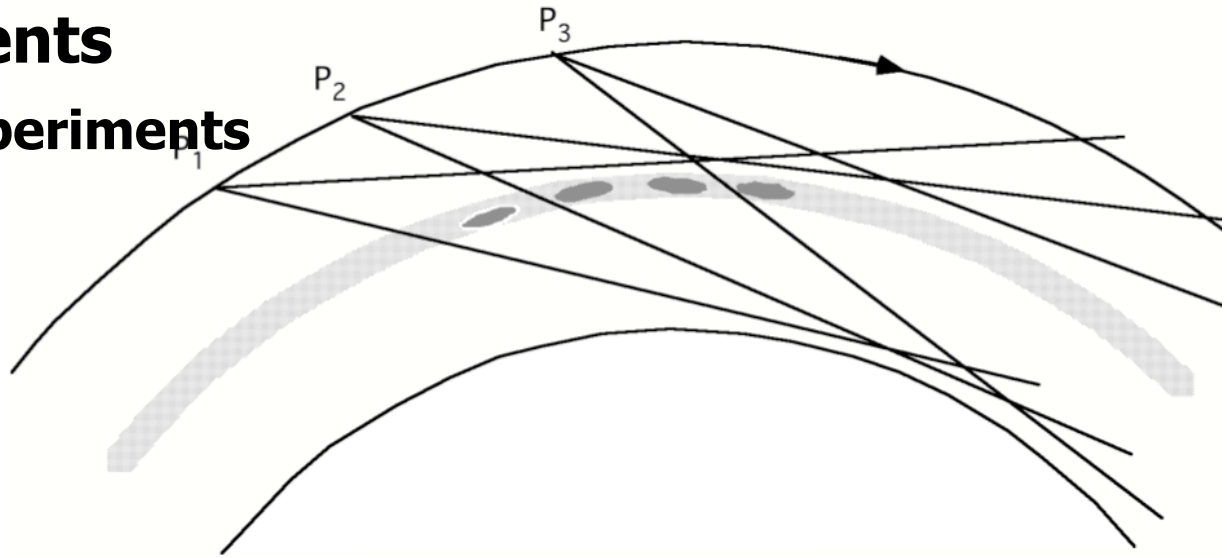
- Physical size (optics, booms, antennas)
- Power, data rate downlink
- Pointing, maneuvering
- Limited control of orbits

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

Cubesats: What can they contribute?

- **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**
- **New regions**
  - ❑ **Dispensable**



Frey, S. et al (2001) *J. Geophys. Res.*, *106*(A10).

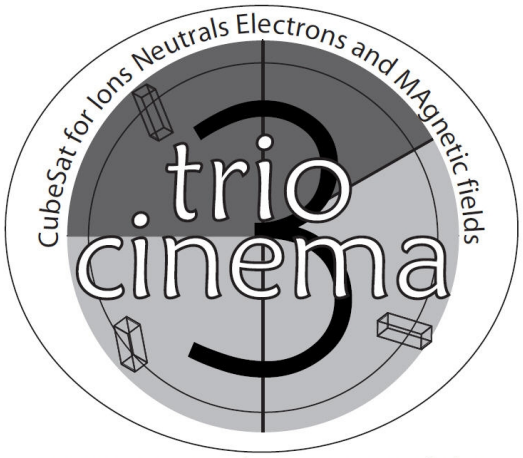
Cubesats: Change of mindset

Powerful concepts:

- **Building to a standard**
- **Containerized launch**

New paradigm:

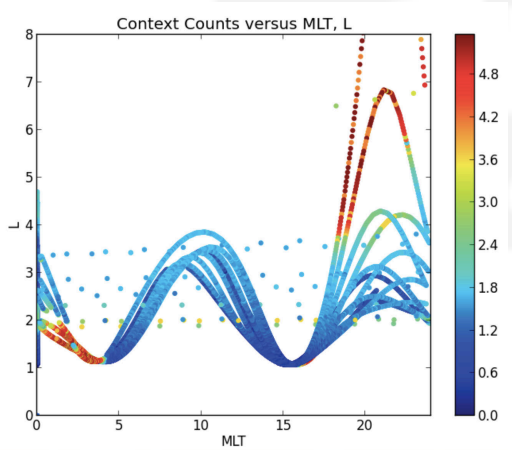
- **Low cost**
- **High risk acceptance**
- **Broad participation:**
  - **high influx of innovation & widespread expertise**

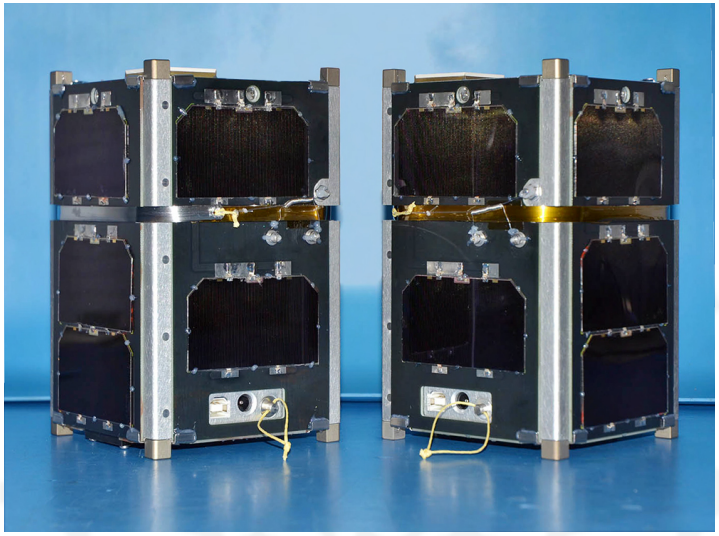


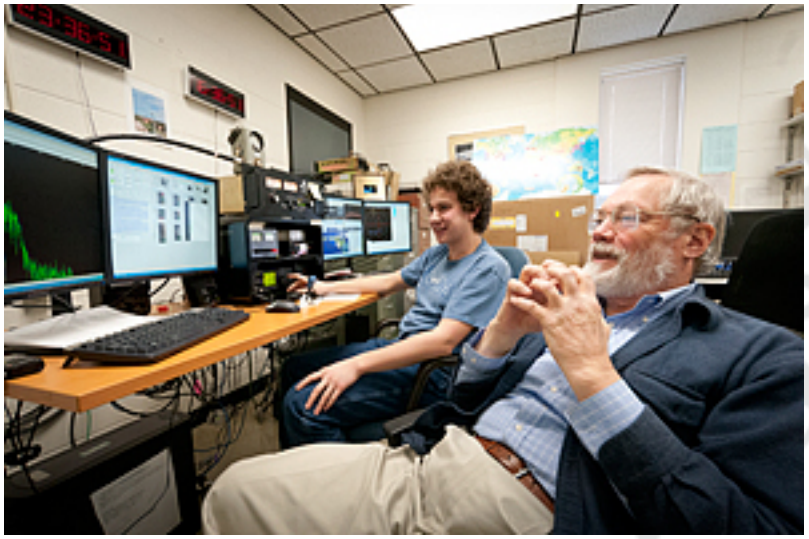
Space Sciences Laboratory, UC Berkeley
Kyung Hee University of South Korea
Imperial College London

- **U. California Berkely & 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 still healthy (17 months)**

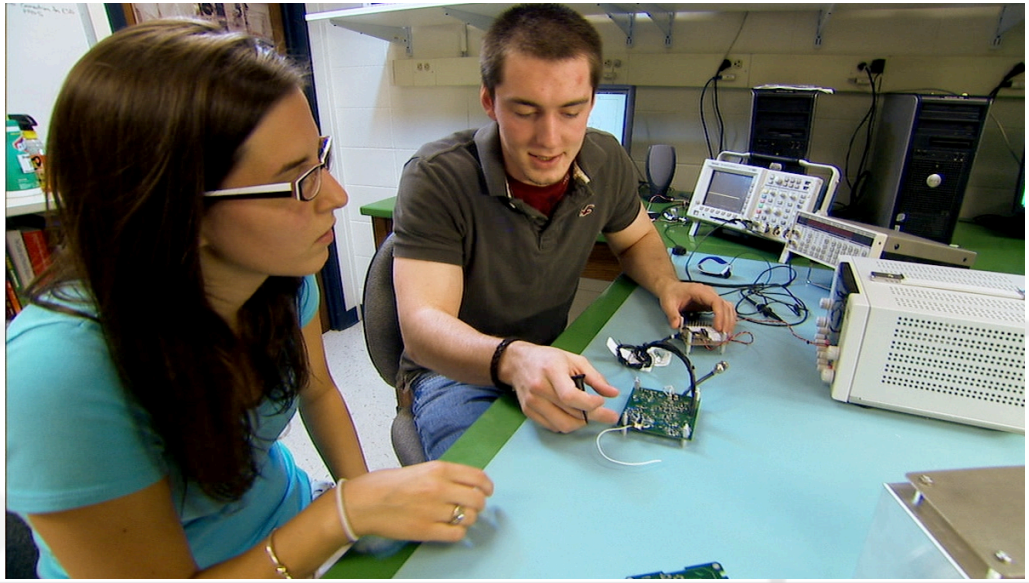
- **U. New Hampshire; Montana St. U & Aerospace Corp.**
- **Relativistic Electron Microbursts**
  - ❑ **2 identical 1.5U cubesats**
  - ❑ **Energetic electrons (0.3-1MeV) with high time resolution (100ms)**
- **Launched Dec 2013**
  - ❑ **One satellite fully operational**
  - ❑ **First light; high quality data**

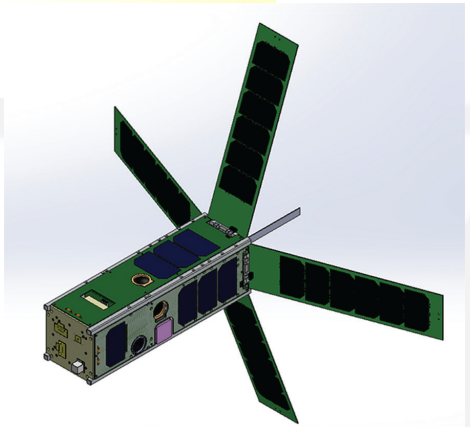




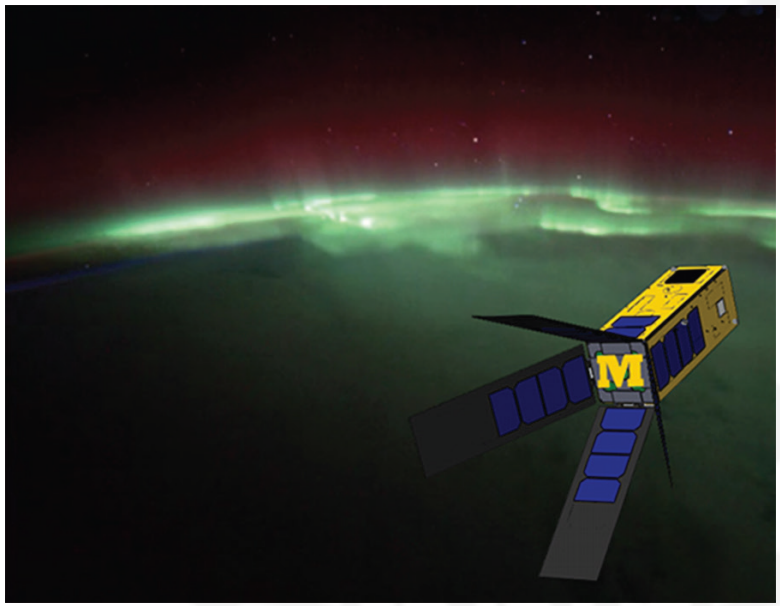


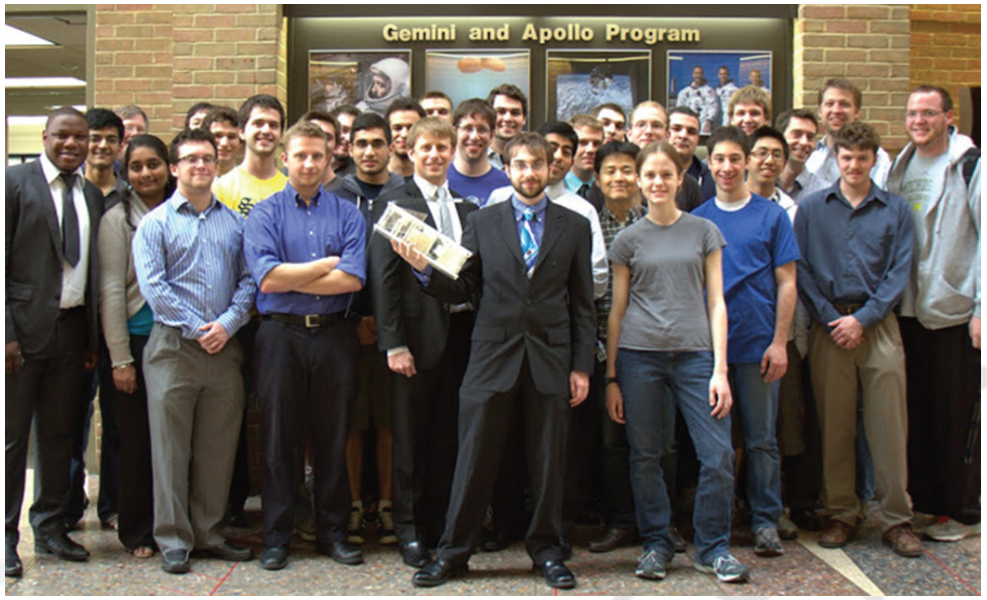
- **NASA Goddard Space Flight Center & Siena College**
- **Terrestrial Gamma Ray Flashes and Lightning**
  - **3U cubesat**
  - **Gamma Rays (to 20MeV); VLF radio and optical**
- **Launched Nov 2013**
  - **2 months to first contact**
  - **Science phase imminent**



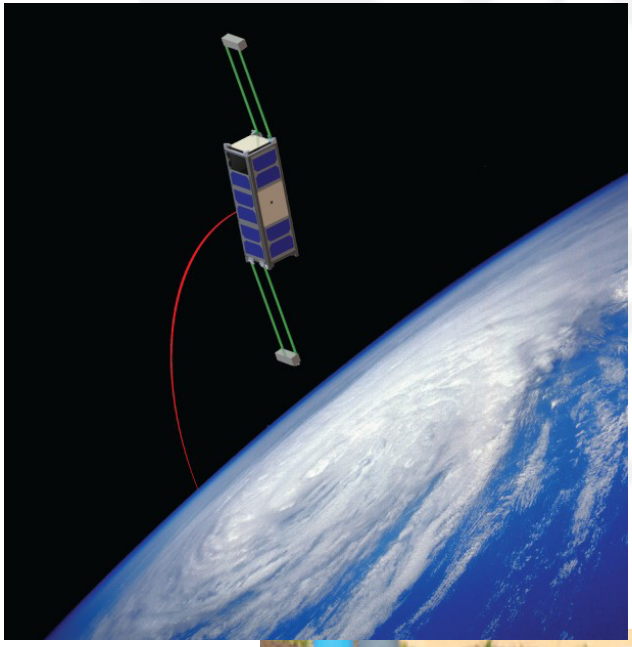


- **U. Michigan & Naval Research Lab**
- **Thermosphere dynamics**
  - **3U cubesat**
  - **Miniature mass spectrometer; density, temperature, winds and composition of neutrals and ions**
- **Launch late 2014**



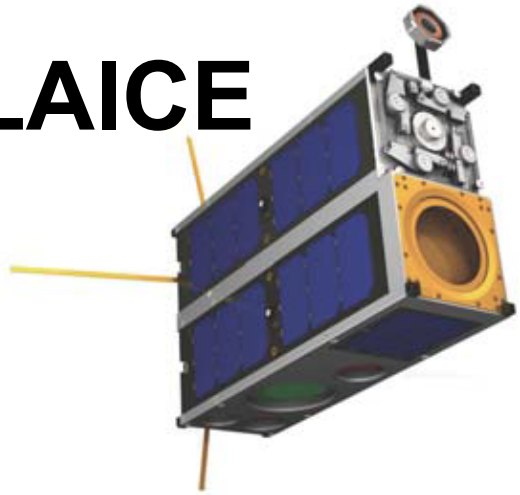


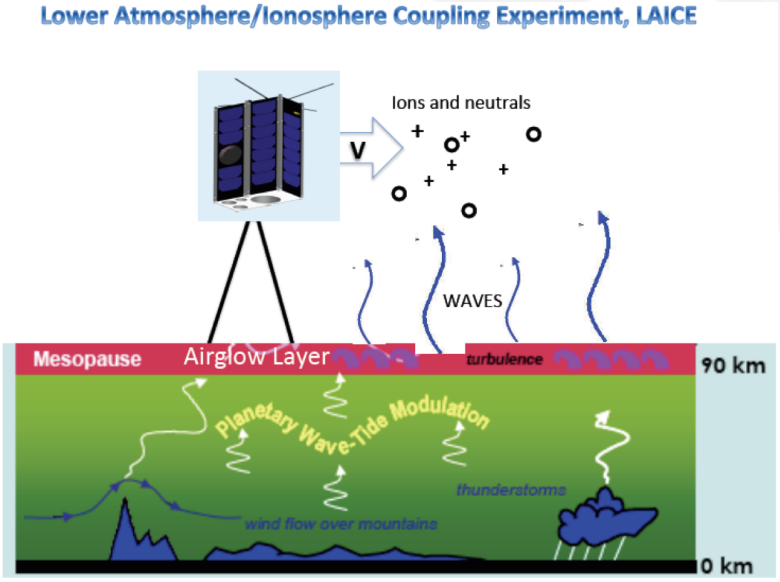
ExoCube



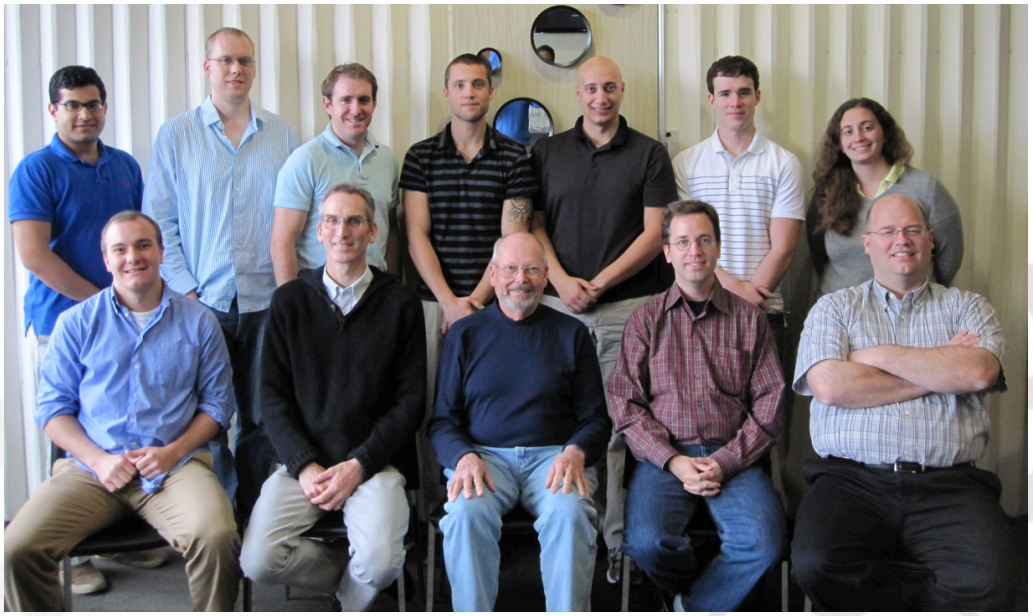
- **Scientific Solutions, Inc; CalPoly; NASA Goddard; U. Wisconsin & U. Illinois**
- **Composition of the upper atmosphere**
  - **3U cubesat**
  - **Miniature mass spectrometer; global density of H, He, and O and ions**
- **Launch Oct 2014**

LAICE





- **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 ~90km**
- **Project Started May 2013**
  - **Expected launch early 2016**



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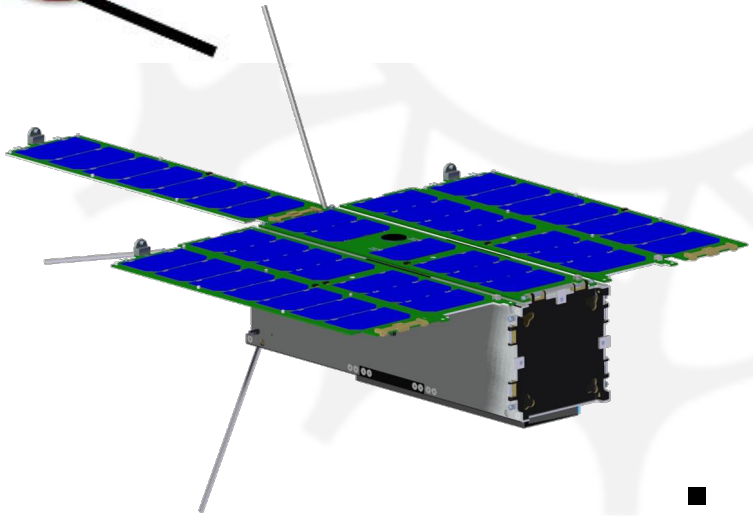

- **Utah St. U. & & HISS (U. Maryland Eastern Shore)**
- **Neutral temperature profiles 90-140km**
  - **3U Boeing Colony cubesat provided by NRO**
  - **High resolution, hyper-spectral imaging spectrometer; Daytime airglow O2 760-770nm**
- **Project Started Sep 2013**