



Geospace Science with Cubesats

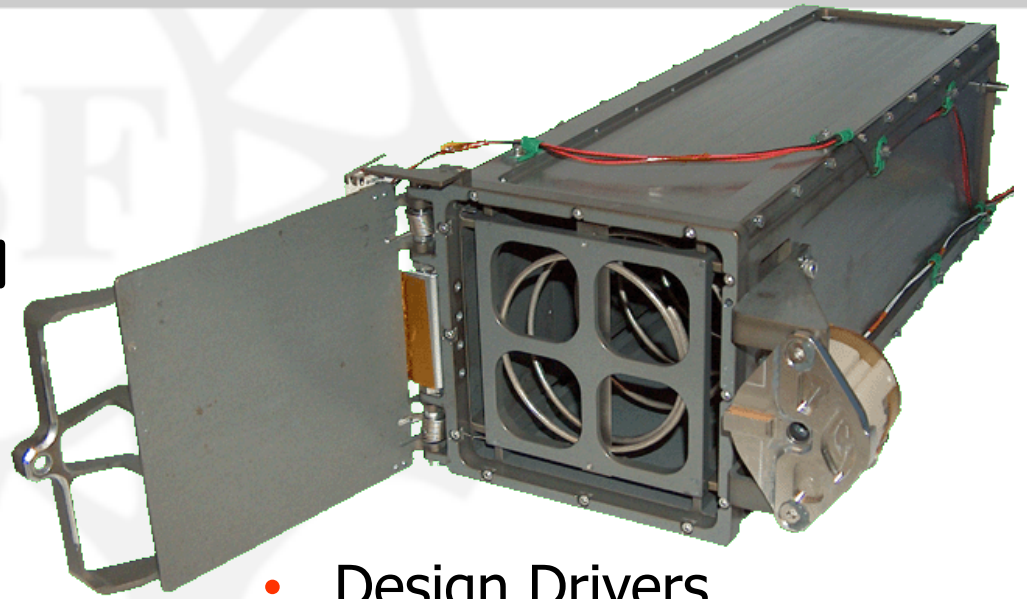
Therese Moretto Jorgensen

**Atmospheric and Geospace Science Division
The National Science Foundation**

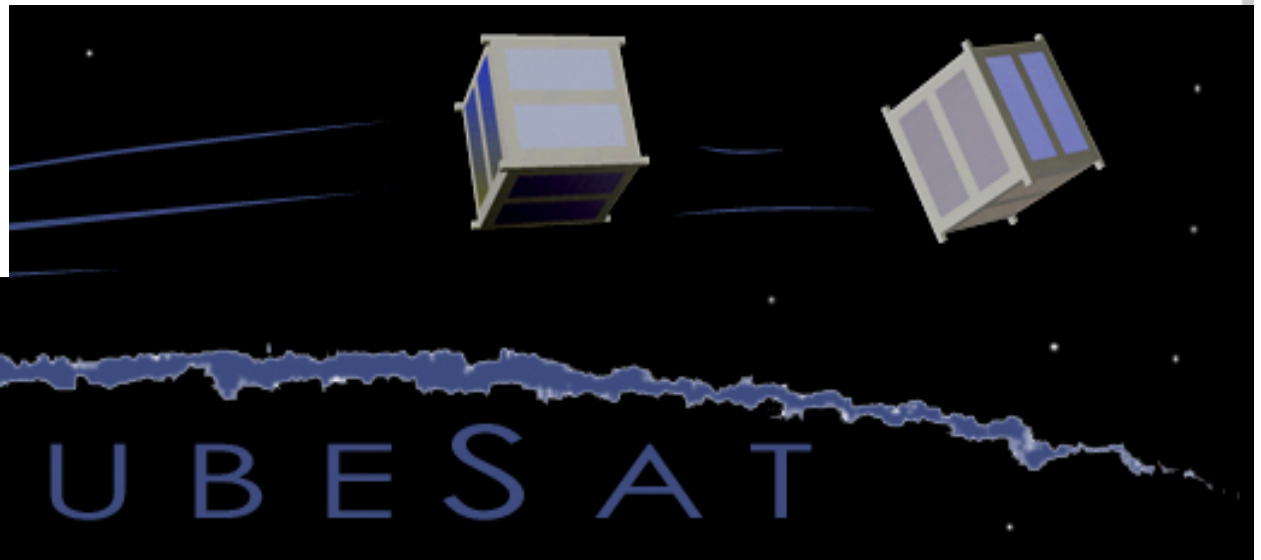
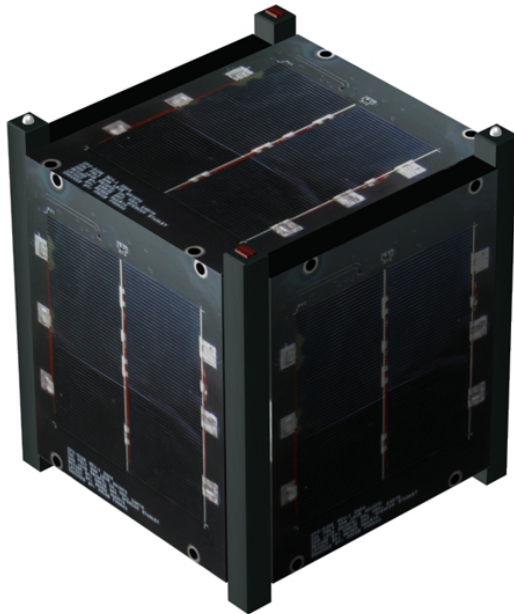
What is a CubeSat?

A pico-satellite Standard

1999 by Puig-Suari, CalPoly
and Twiggs, Stanford

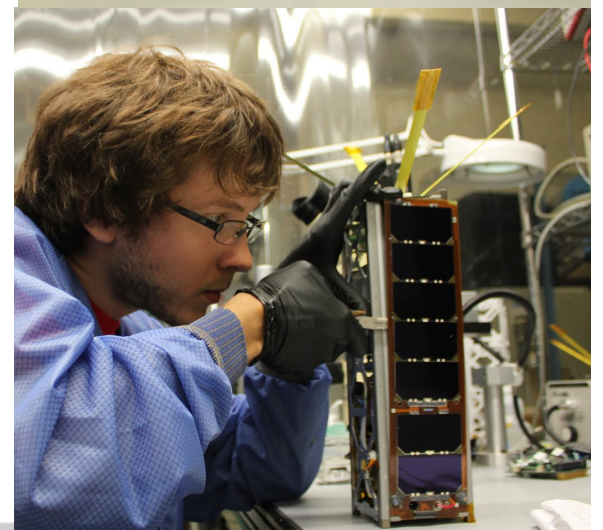
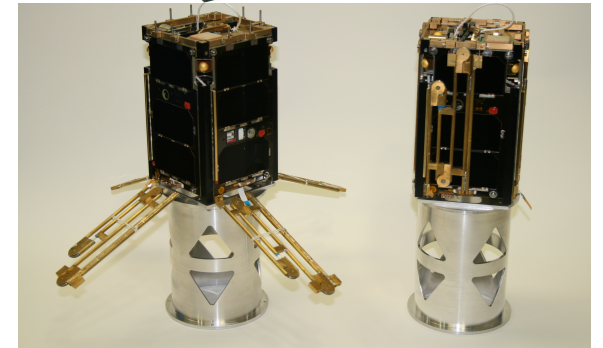
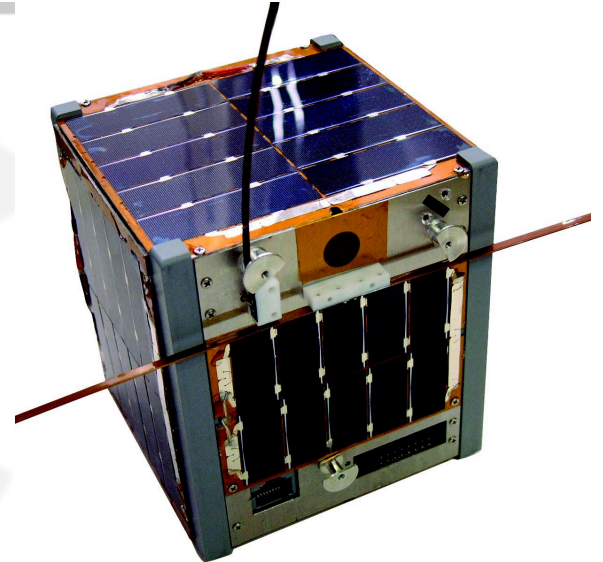


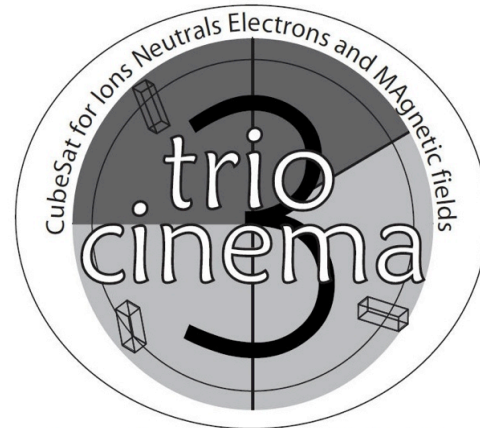
- Design Drivers
 - Simple and low-cost, but safe
 - Available COTS components
 - P-POD deployer system



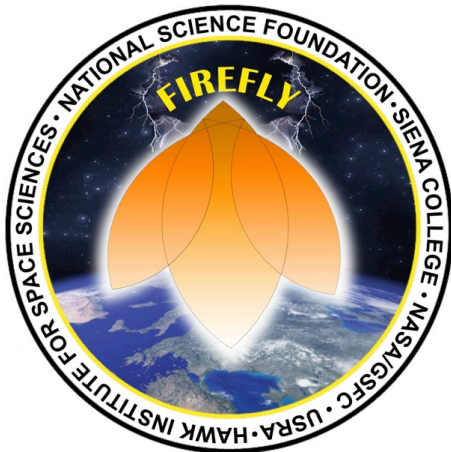
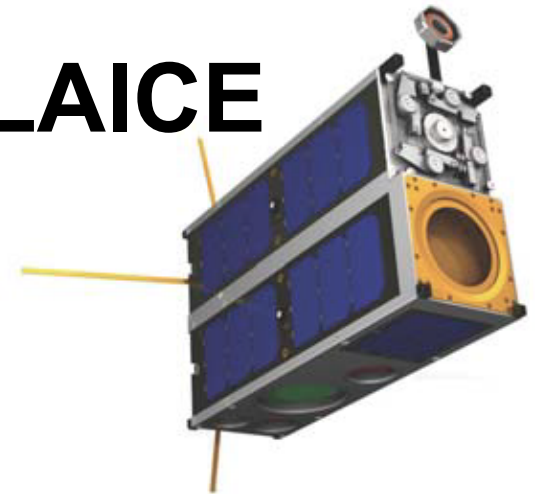
NSF Cubesat Program since 2008

- **Geospace & atmospheric science and education**
- **2 new projects per year**
- **>80 unique missions proposed**
- **12 projects funded**
- **Grants \$900,000 total cost and 3 year duration**



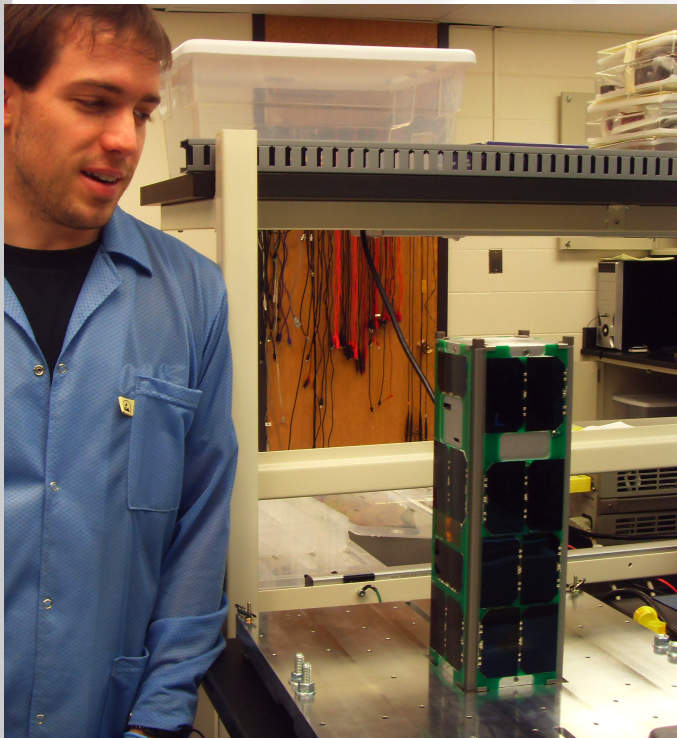


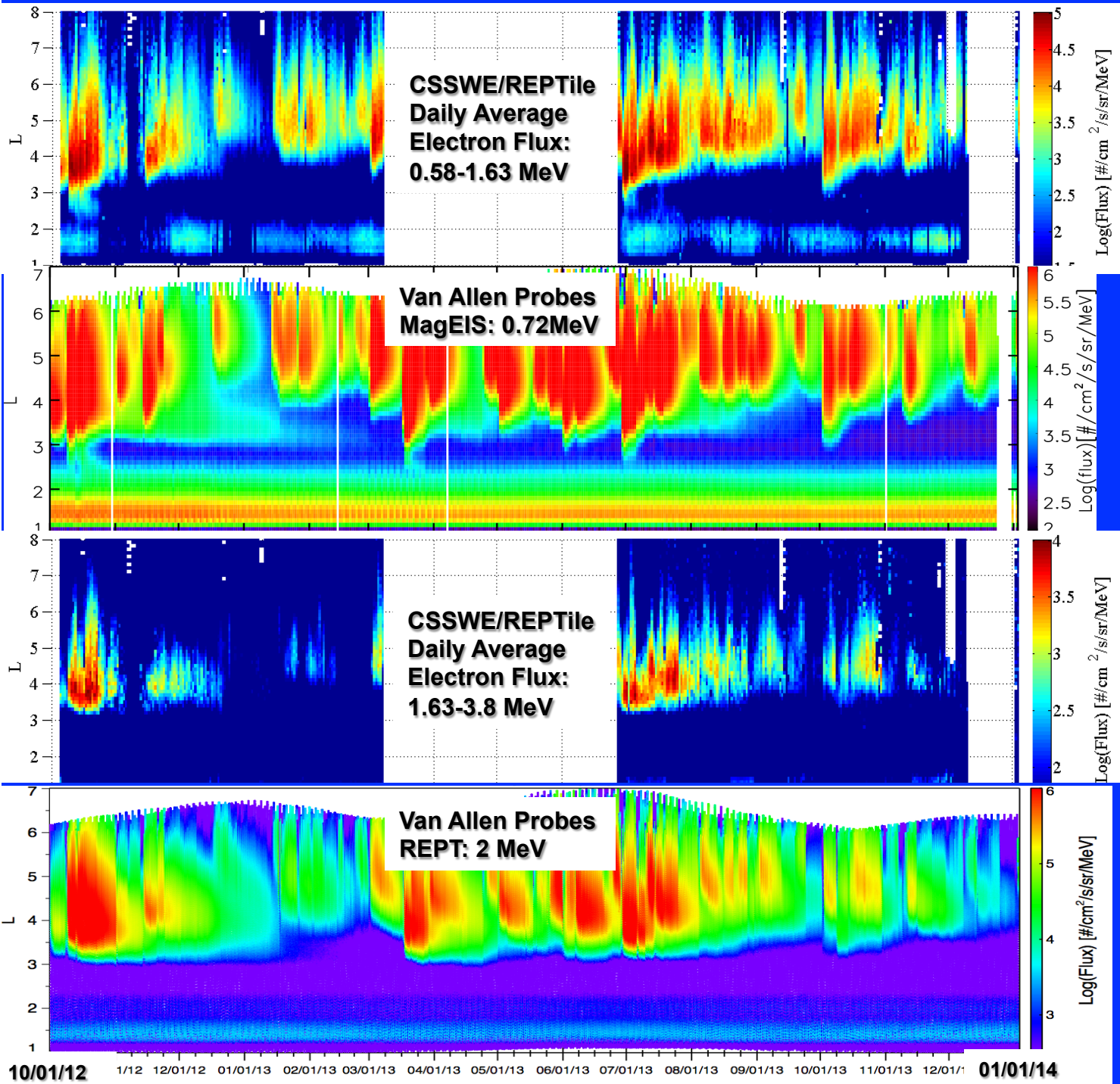
LAICE





- **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**





Congratulations!



Science Summary of NSF FIREBIRD-I and -II Missions

PIs: Harlan Spence (UNH) and David Klumpar (MSU)



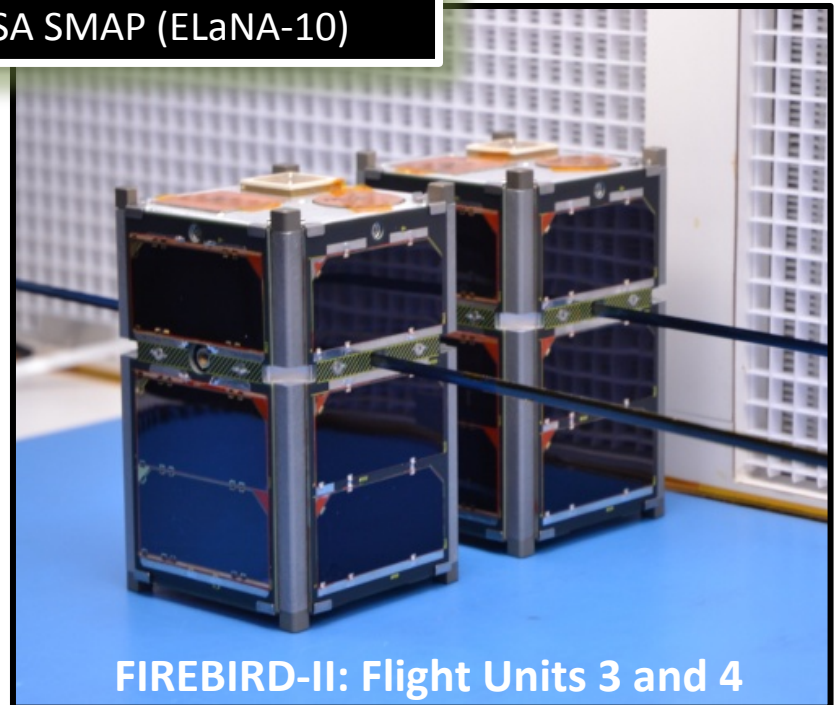
FB-I LAUNCHED: Dec 6, 2013
VAFB Atlas-5 NROL-39

FB-II Launch scheduled Dec 15, 2014
VAFB Delta-II 7320 NASA SMAP (ELaNA-10)



FIREBIRD- I: Flight Units 1 and 2

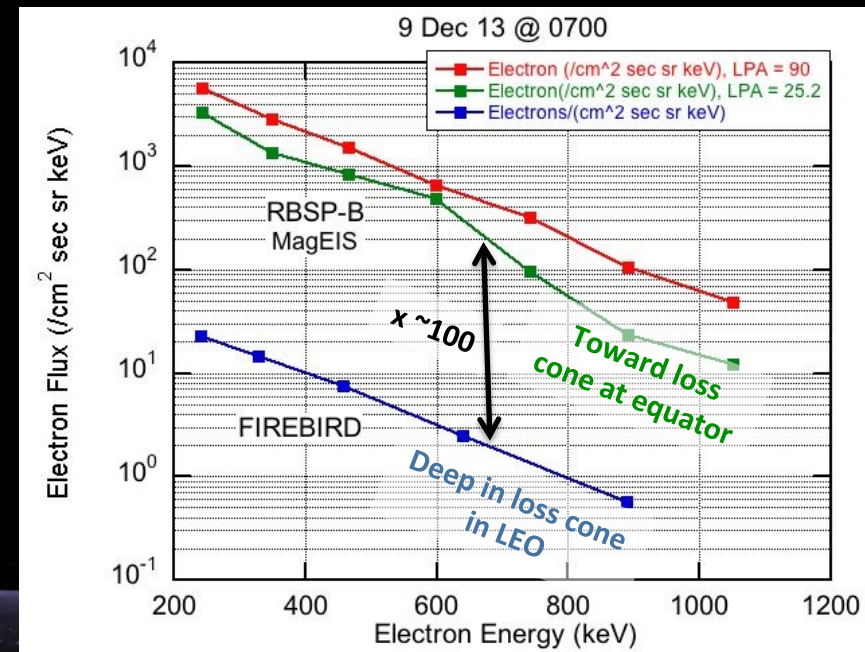
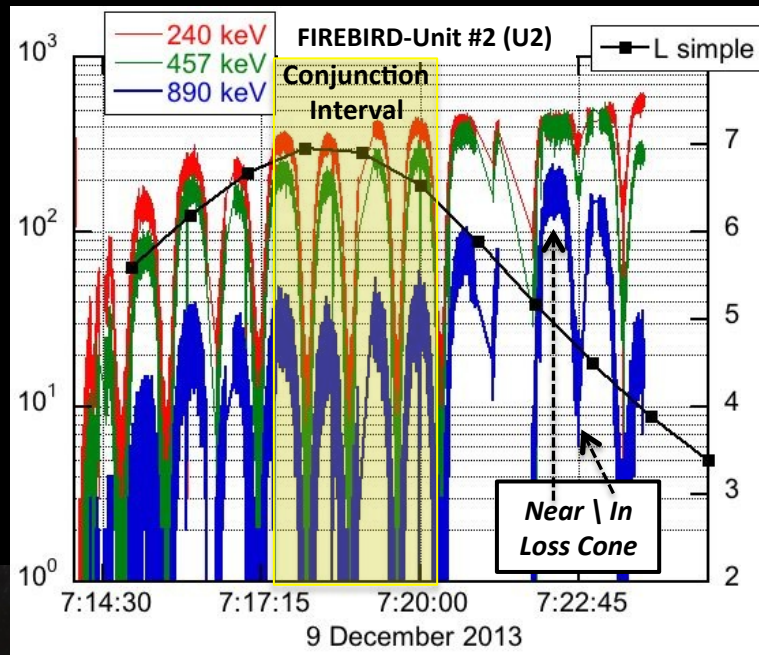
**Providing excellent science results;
FU1: 12/13 - 1/14, FU2: 4/14 - present**



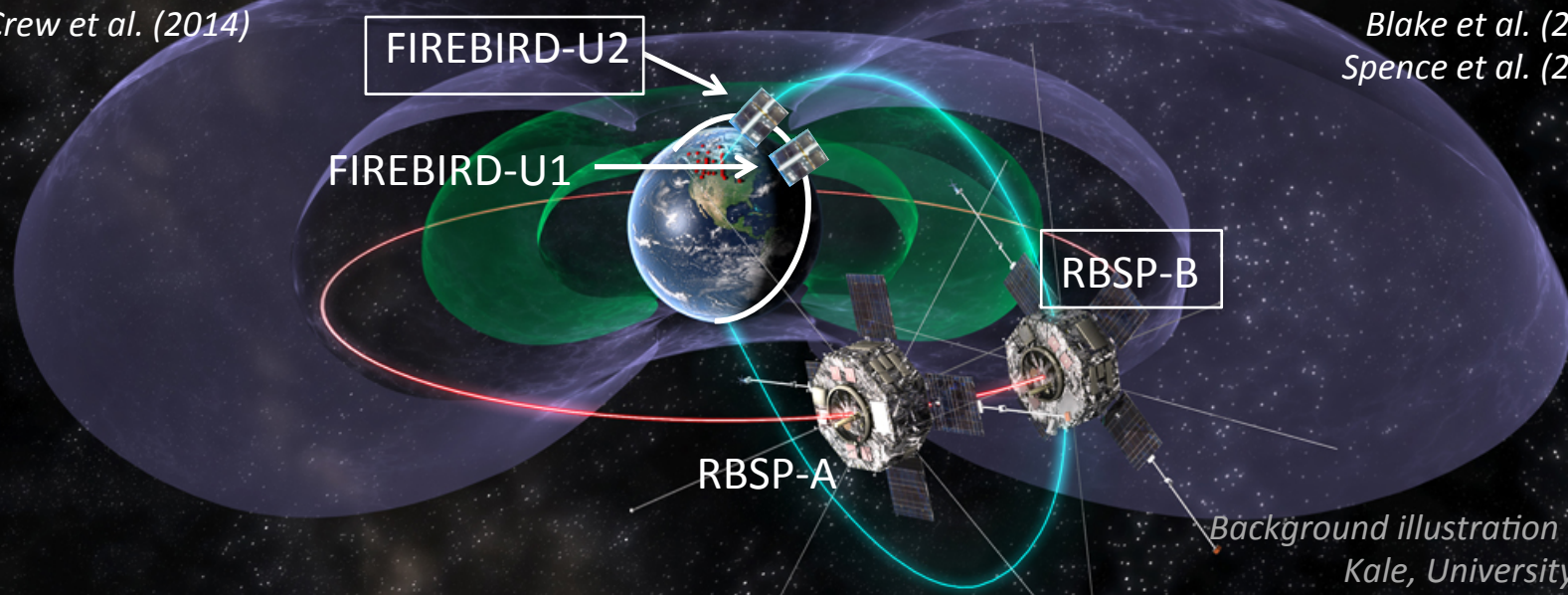
FIREBIRD-II: Flight Units 3 and 4

**Improved version of FB-I mission;
Ready for launch in December 2014**

Comparison of Conjugate Spectral Shape and Electron Intensity (250 – 1000 keV) In/Near Loss Cone at LEO (FB-U2) and Near Equator (RBSP-B) at L ~ 6.5

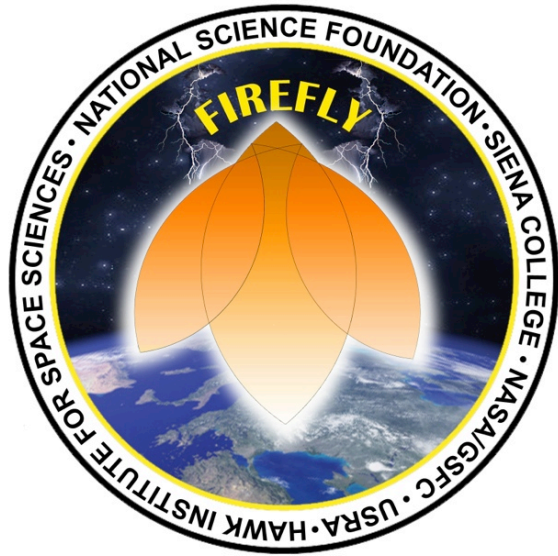


Crew et al. (2014)

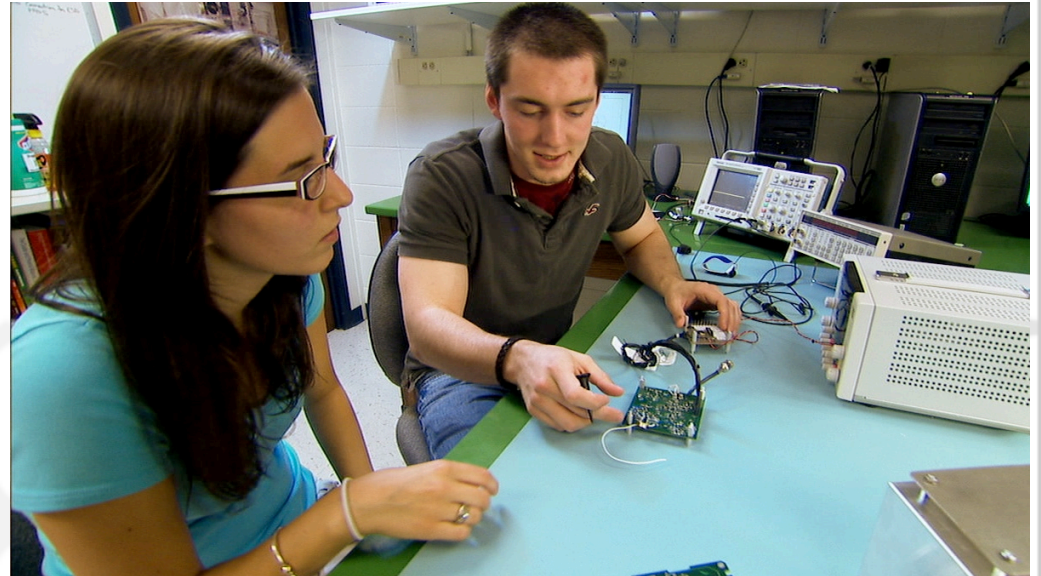


Blake et al. (2014)
Spence et al. (2014)

Background illustration courtesy A. Kale, University of Alberta



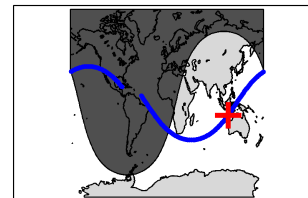
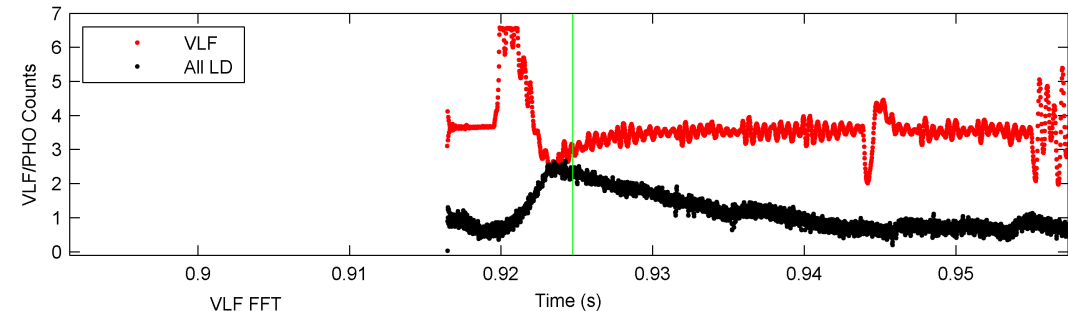
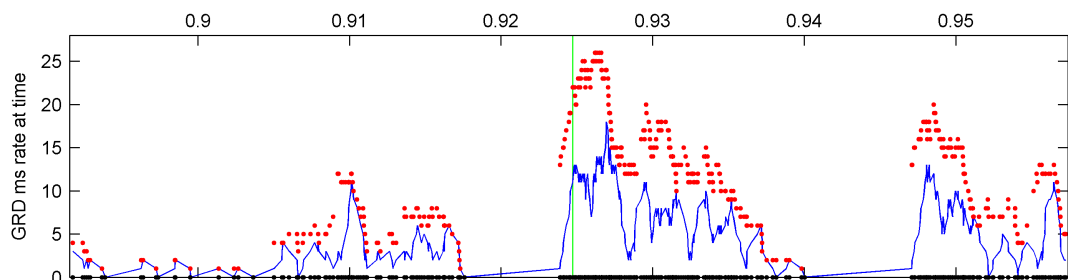
- **NASA Goddard Space Flight Center & Siena College**
- **Terrestrial Gamma Ray Flashes and Lightning**
 - ❑ **3U cubesat**
 - ❑ **Gamma Rays (to 20MeV); VLF radio and optical**
- **Launched Nov 2013**
 - ❑ **2 months to first contact**
 - ❑ **Data collection and analysis ongoing**



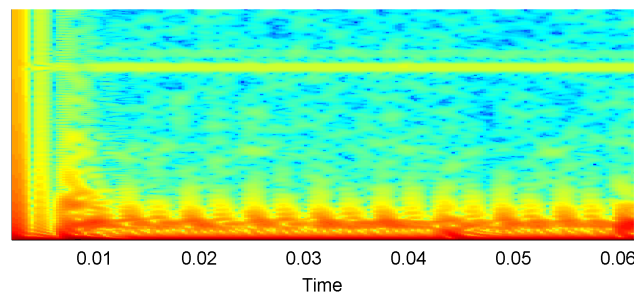
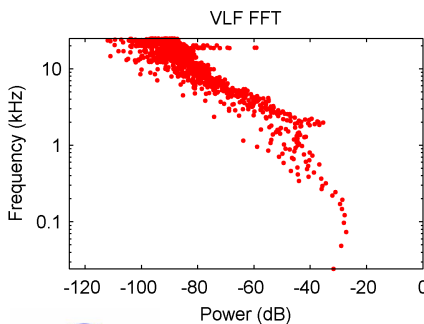
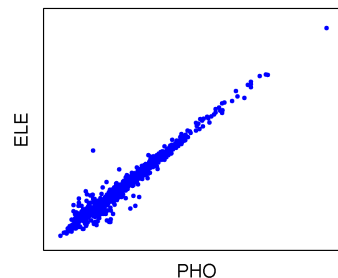


Firefly Combined Survey Plot

UT Time: 2014.05.21 16:55:6.820 Position: -13.905 N 114.178 E, 489 km



Fast vs. slow shaper

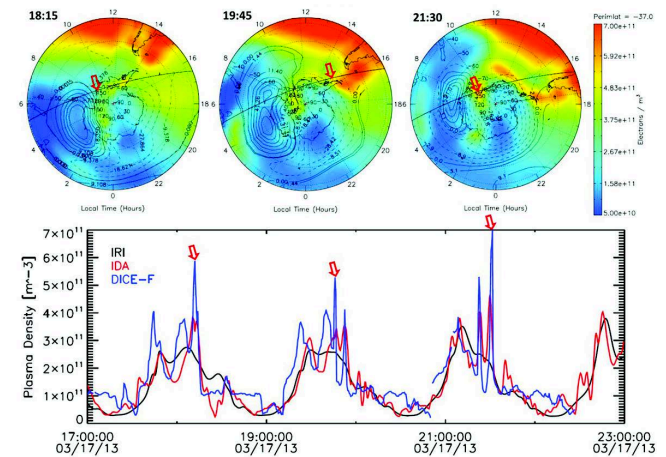


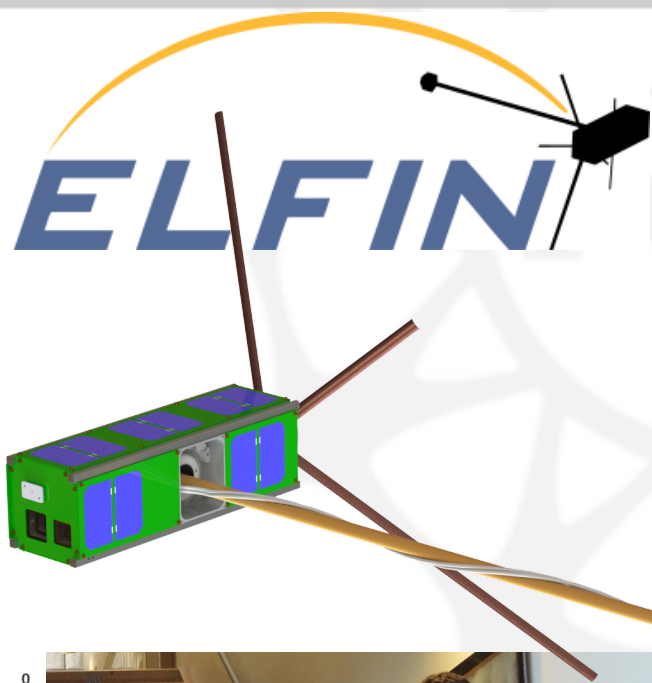
We gratefully acknowledge support from the National Science Foundation



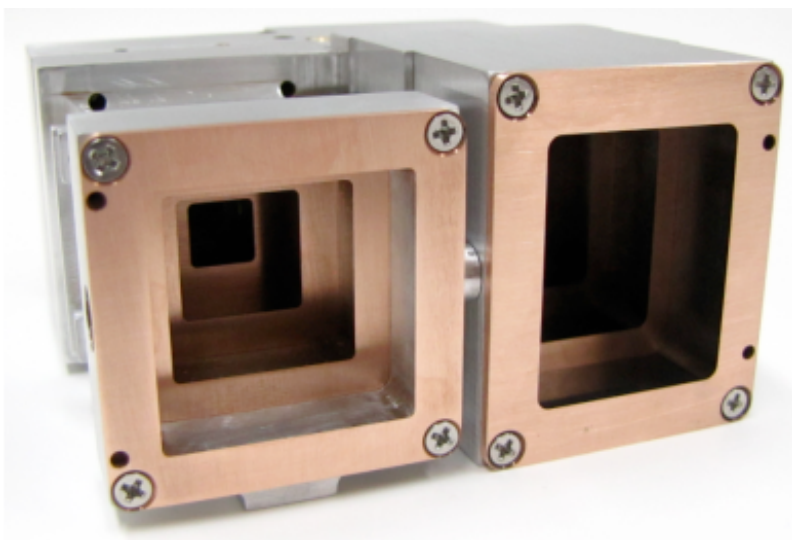
Accomplishments

- **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**



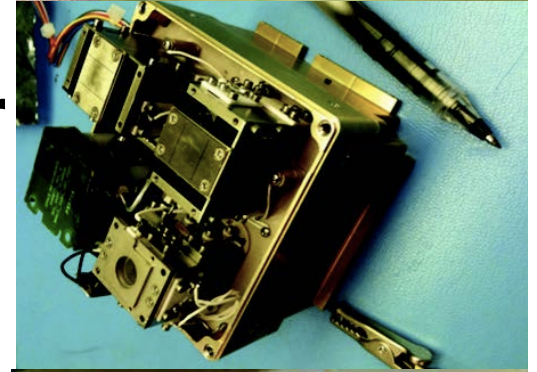
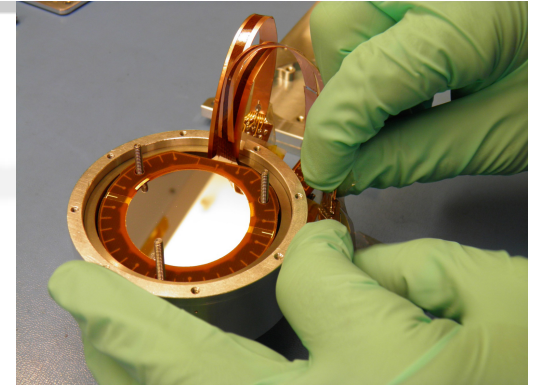


- **UCLA**
- **Pitch angle distribution of relativistic electrons and ions**
 - ❑ **3U cubesat; spinning @20rpm**
 - ❑ **Full angular distribution of electrons (50keV-5MeV) and ions (50-300keV); Magnetic field**
- **Project Started August 2014**
 - ❑ **Jointly funded with NASA**



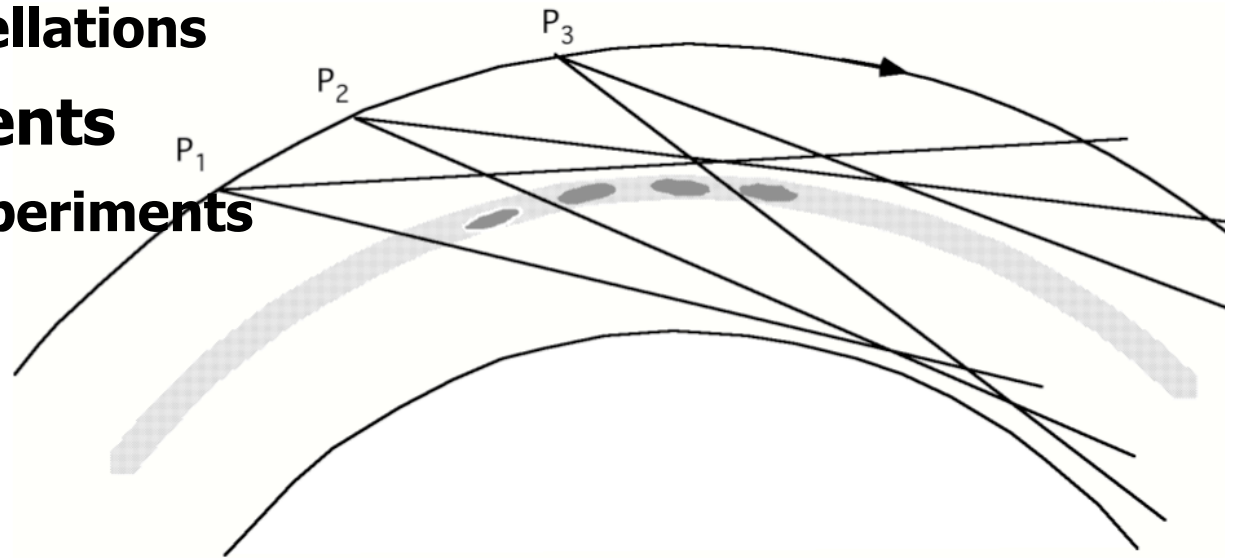
Cubesats in LEO

- **can provide most desired space physics parameters**
 - ❑ **Capability already demonstrated, or will be soon for: in-situ fields, energetic and supra thermal particles, plasma and neutrals densities, winds, and composition, VLF and UHF receivers, and gamma ray detectors**
 - ❑ **Capability documented and will be demonstrated soon for: remote sensing of aurora, air-glow, radio occultation, and simple solar imaging and flare observations (e.g. X-ray)**



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



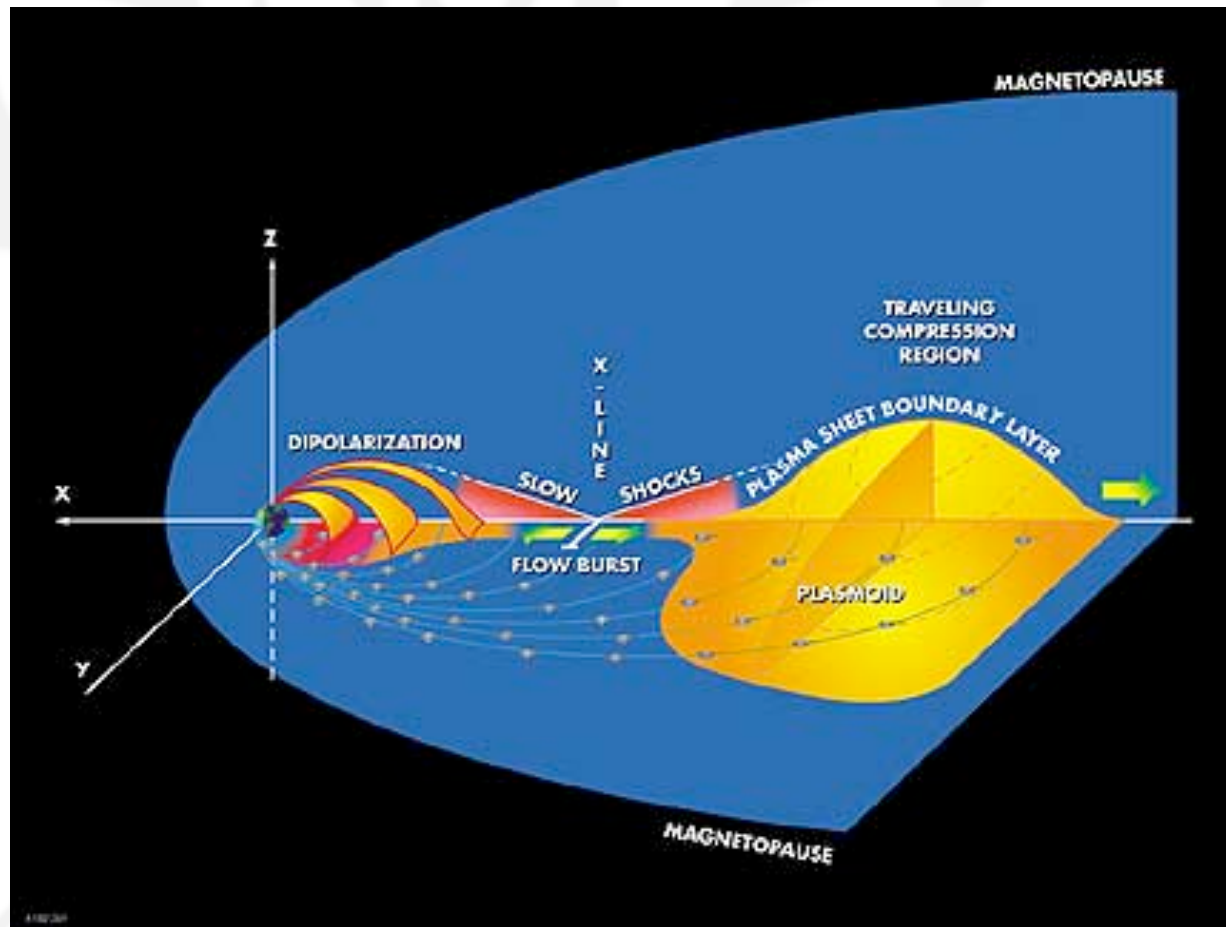
Frey, S. et al (2001) *J. Geophys. Res.*, 106(A10).

Cubesats in HEO & Beyond

- **Exciting potential**
 - realize mag-con type missions and multi-point solar and solar wind monitoring
- **Main technical challenges include:**
 - communication and power (related)
 - radiation hardness
 - maneuverability (propulsion and formation flying)



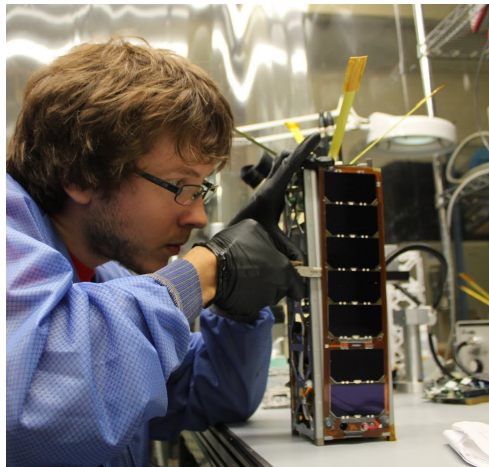
Magnetospheric Constellation

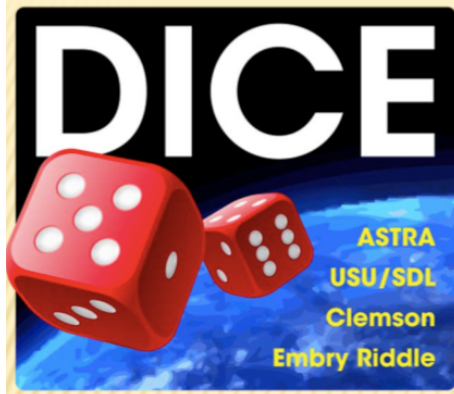


Draco: Dynamic Response and Coupling Observatory



- **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



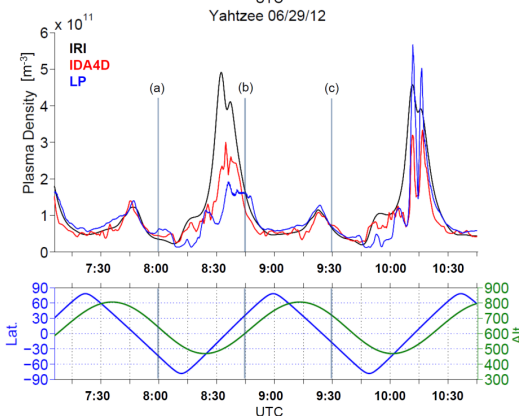
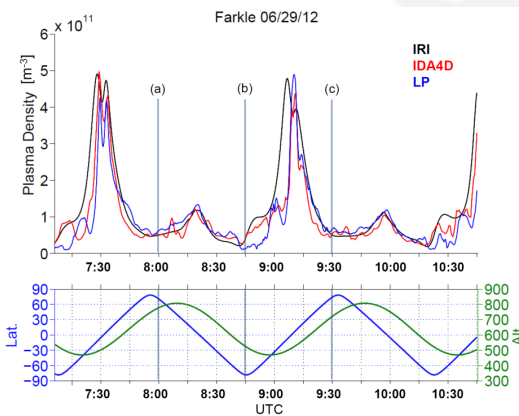


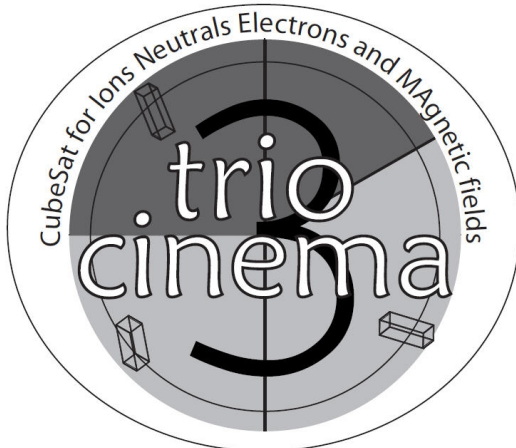
- **ASTRA, Inc. & Utah St. U.**
- **Ionospheric Storm Enhanced Density structures**

- ❑ **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**





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

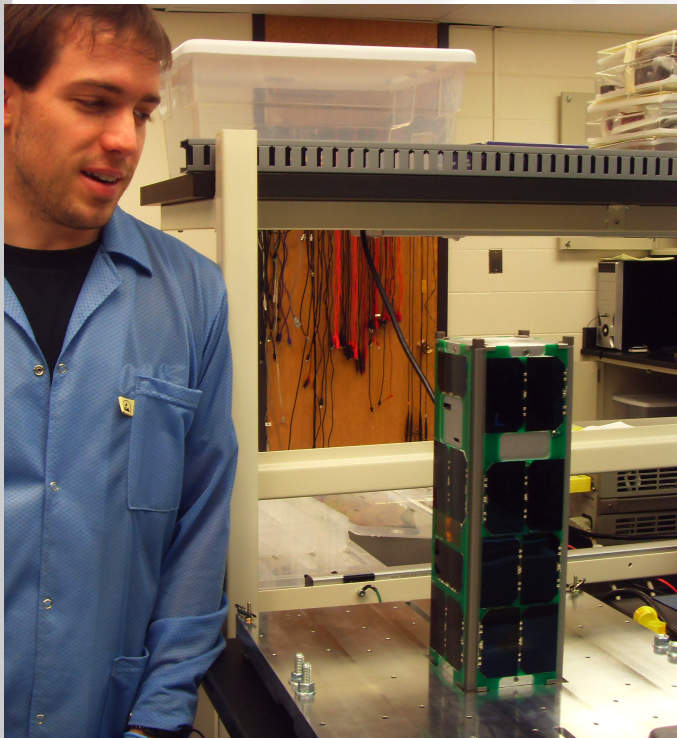


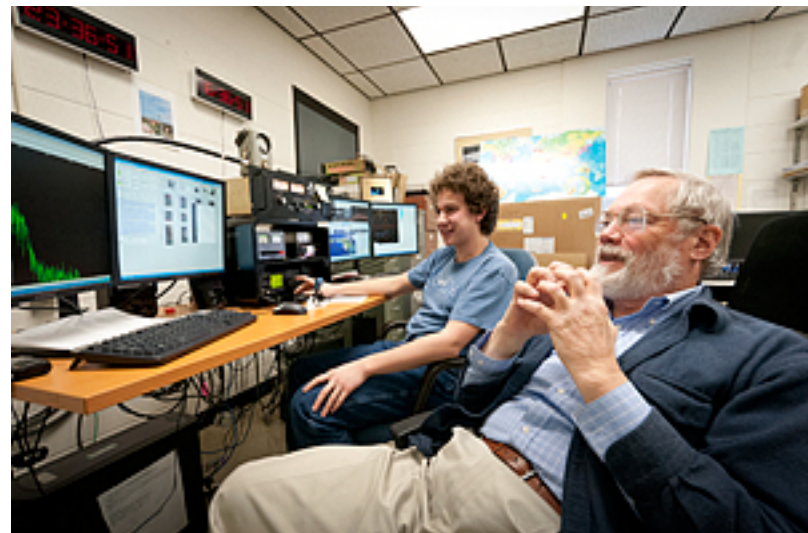
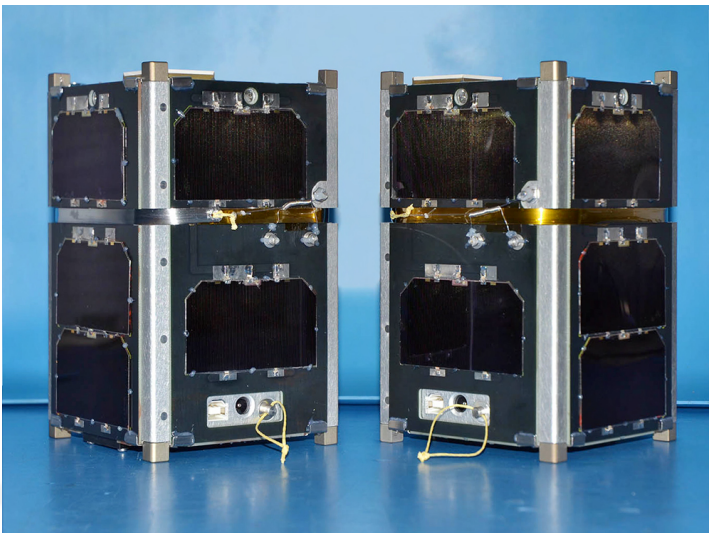
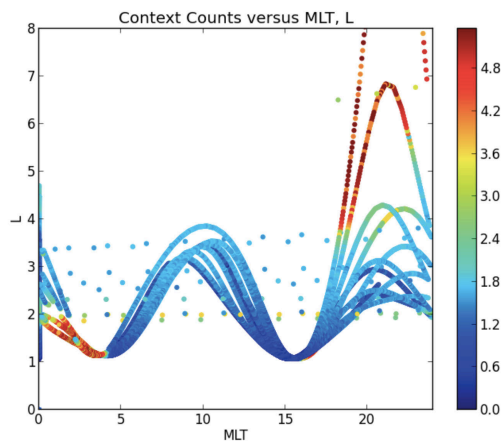
- **U. California Berkely & International collaborators**
- **Ring current dynamics**
 - ❑ **3U cubesat**
 - ❑ **Energetic ions, electrons and neutral particles (4-20keV)**
- **Launched Sep 2012**
 - ❑ **Limited mission success; comm problems; some magnetic field data**
 - ❑ **Spacecraft still healthy (17 months)**



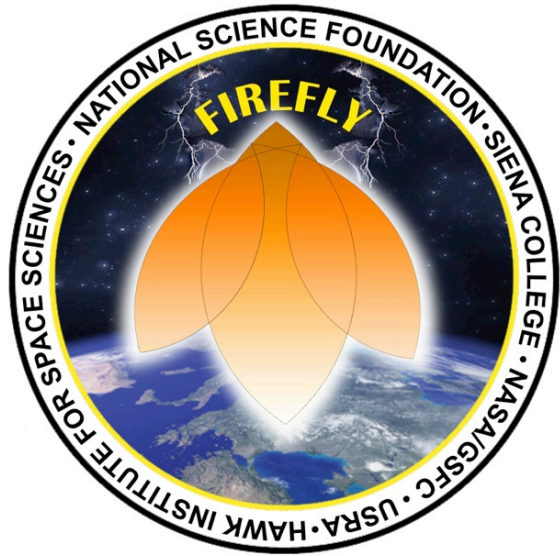


- **U. Colorado, Boulder**
- **Solar Proton Events & Radiation belt dynamics**
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 - ❑ **Complete mission success**
 - ❑ **still operational (17 months)**

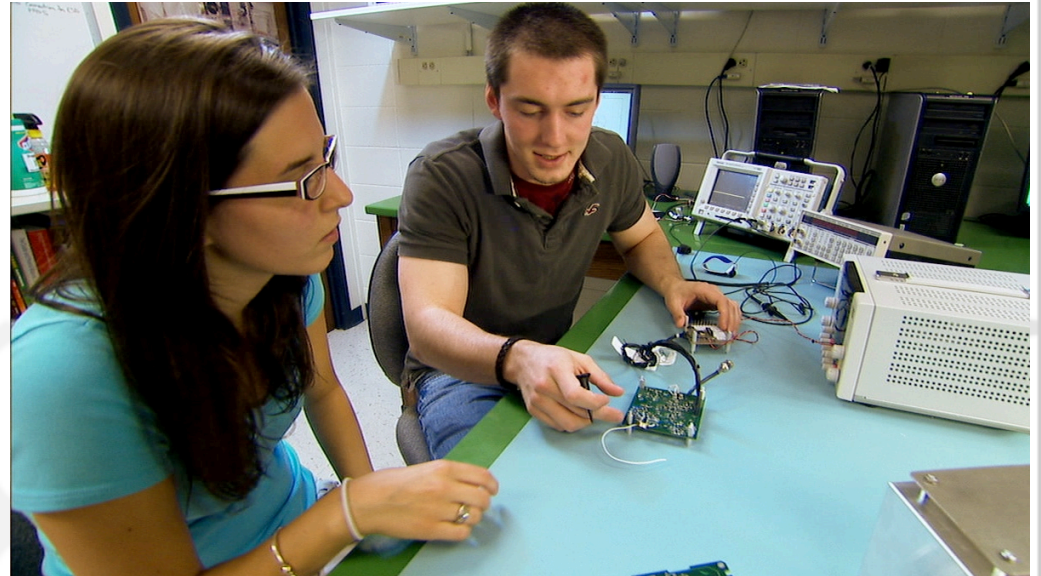


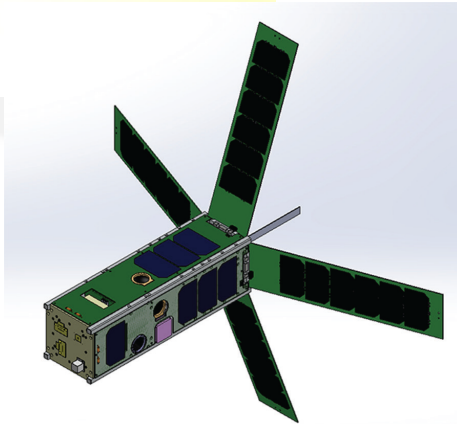


- **U. New Hampshire; Montana St. U & Aerospace Corp.**
- **Relativistic Electron Microbursts**
 - ❑ **2 identical 1.5U cubesats**
 - ❑ **Energetic electrons (0.3-1MeV) with high time resolution (100ms)**
- **Launched Dec 2013**
 - ❑ **One satellite fully operational**
 - ❑ **First light; high quality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

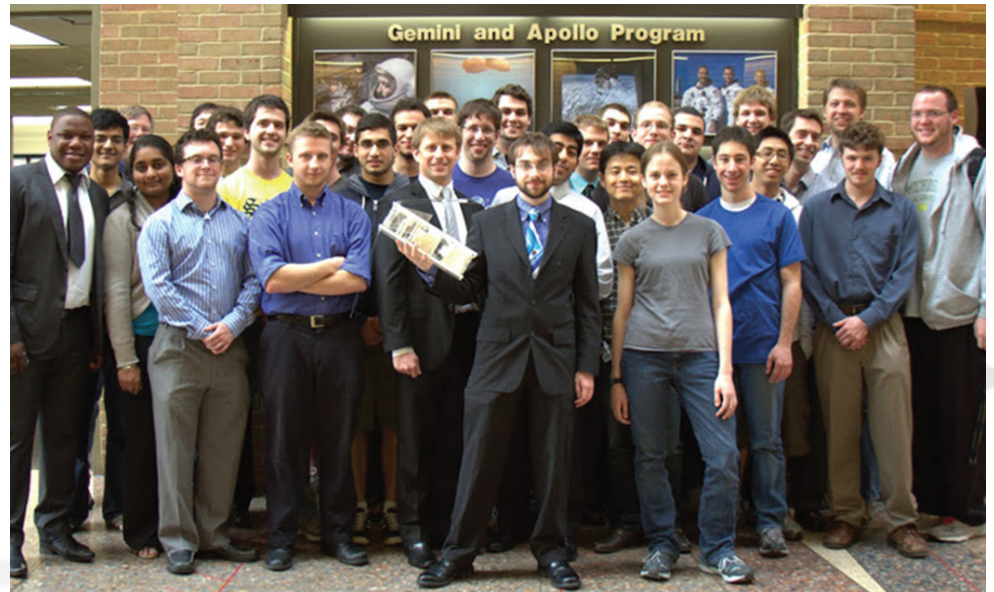
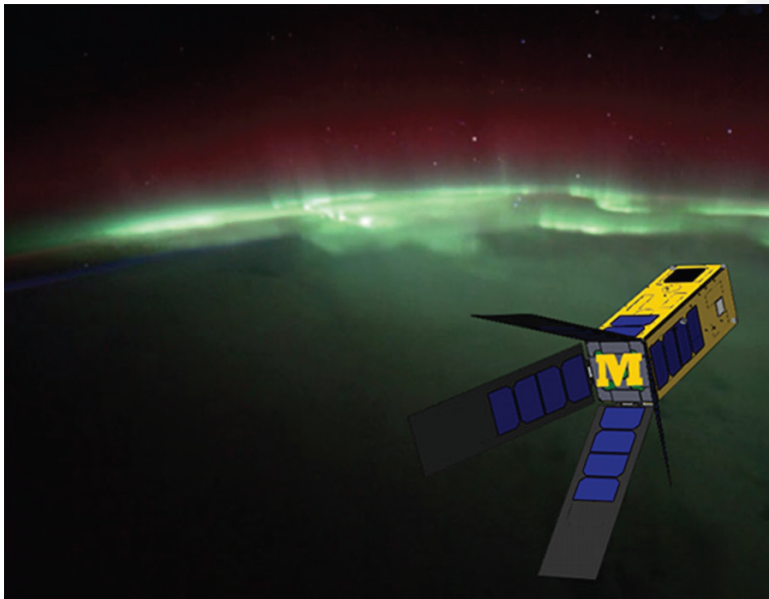


- **NASA Goddard Space Flight Center & Siena College**
- **Terrestrial Gamma Ray Flashes and Lightning**
 - ❑ **3U cubesat**
 - ❑ **Gamma Rays (to 20MeV); VLF radio and optical**
- **Launched Nov 2013**
 - ❑ **2 months to first contact**
 - ❑ **Science phase imminent**

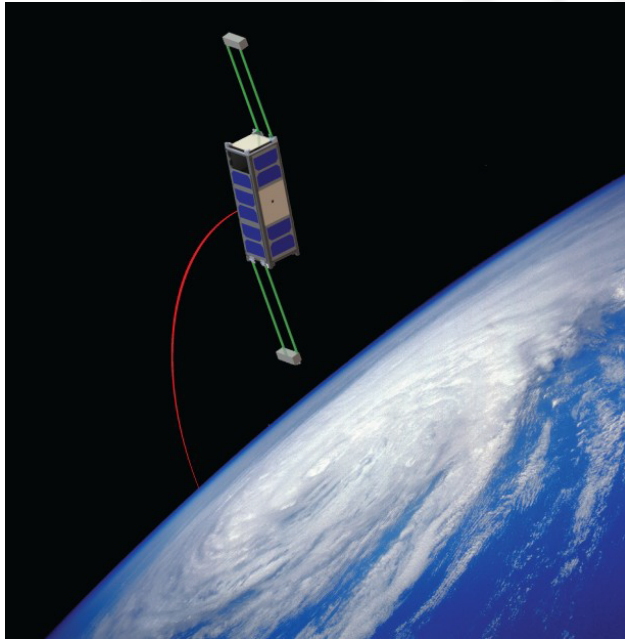




- **U. Michigan & Naval Research Lab**
- **Thermosphere dynamics**
 - ❑ **3U cubesat**
 - ❑ **Miniature mass spectrometer; density, temperature, winds and composition of neutrals and ions**
- **Launch late 2014**



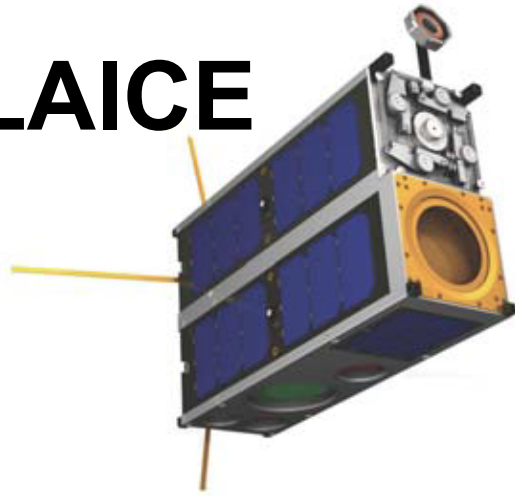
ExoCube



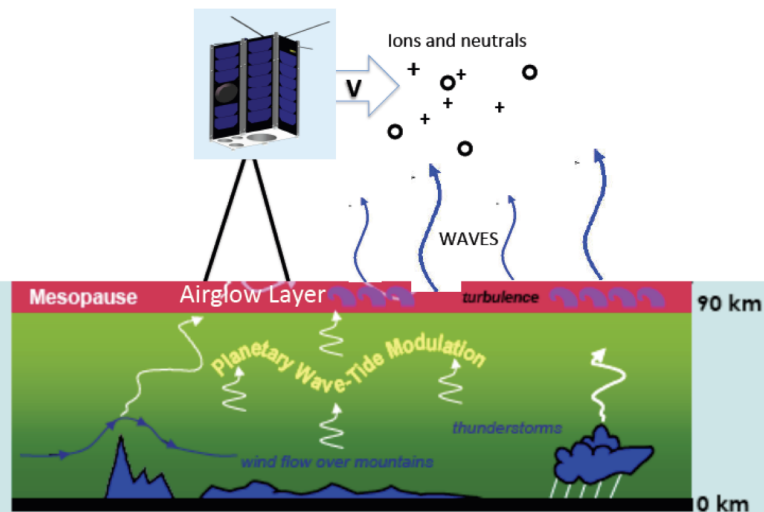
- **Scientific Solutions, Inc; CalPoly; NASA Goddard; U. Wisconsin & U. Illinois**
- **Composition of the upper atmosphere**
 - ❑ **3U cubesat**
 - ❑ **Miniature mass spectrometer; global density of H, He, and O and ions**
- **Launch Oct 2014**



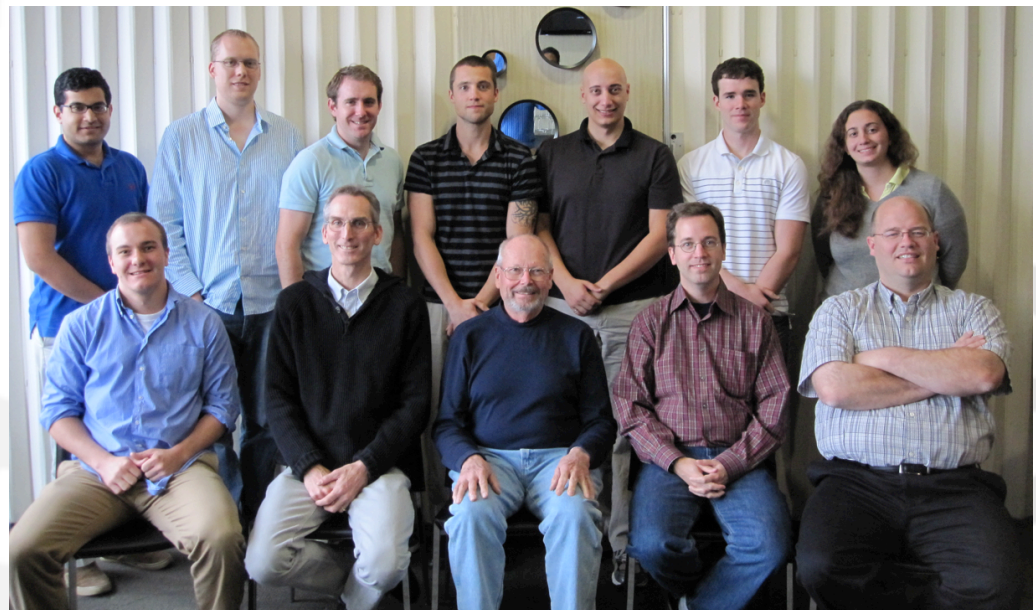
LAICE

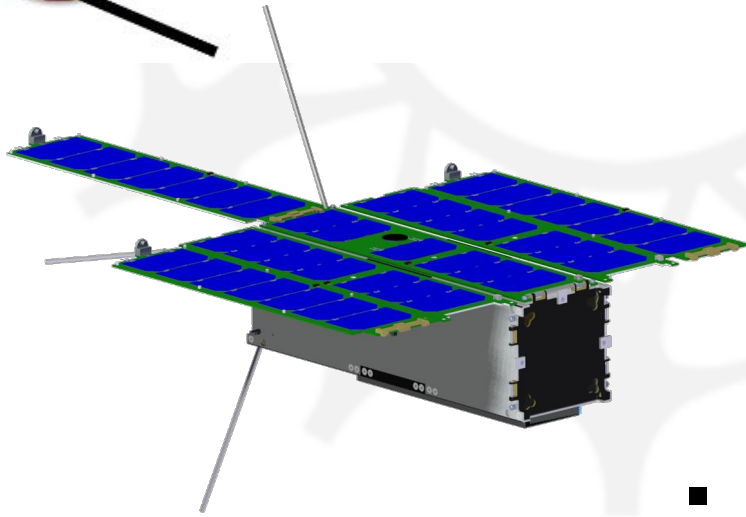


Lower Atmosphere/Ionosphere Coupling Experiment, LAICE

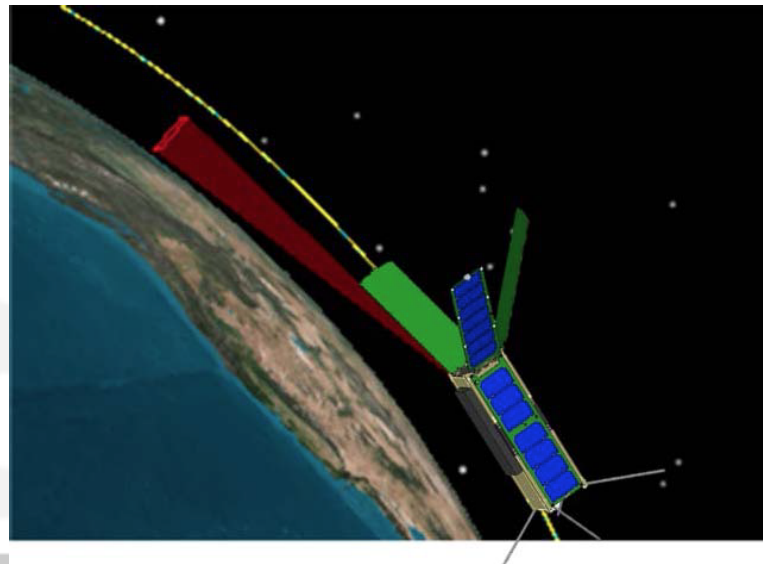
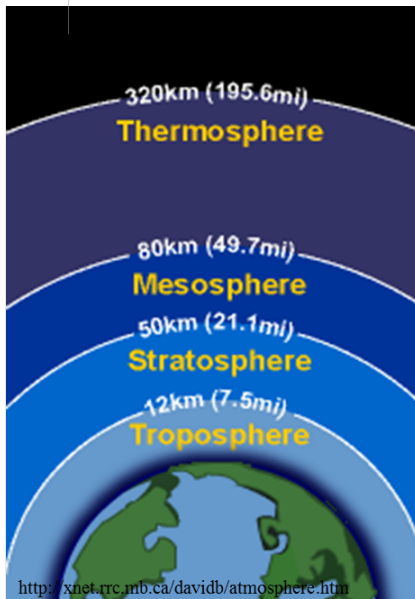


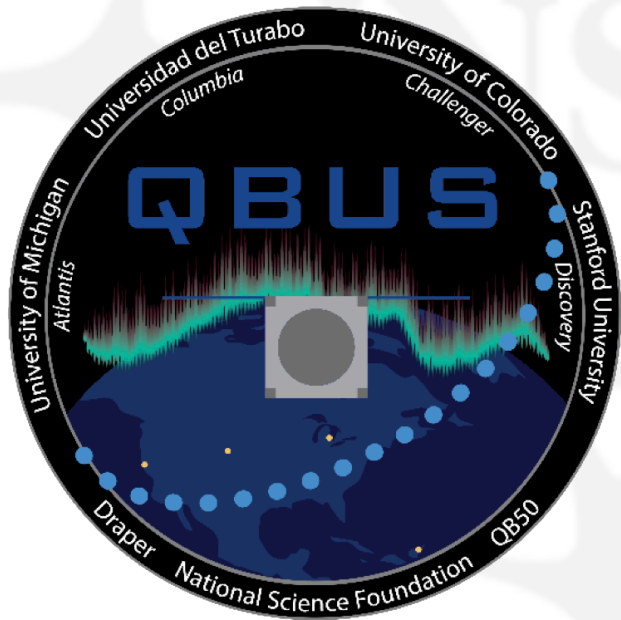
- **Virginia Tech; U. Illinois; Aerospace Corp. & NWRA, Inc.**
- **Atmospheric gravity waves**
 - ❑ **6U cubesat**
 - ❑ **In-situ and remote sensing; plasma and neutral temperature and density; Airglow ~ 90 km**
- **Project Started May 2013**
 - ❑ **Expected launch early 2016**

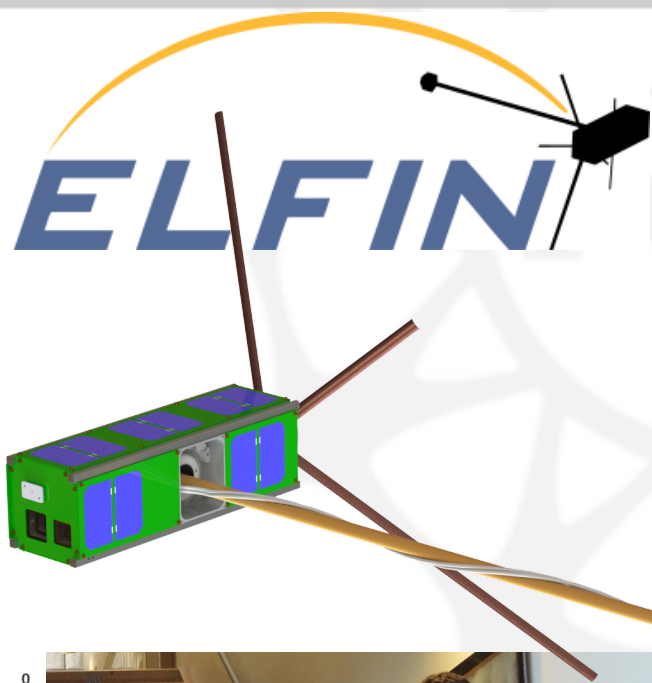




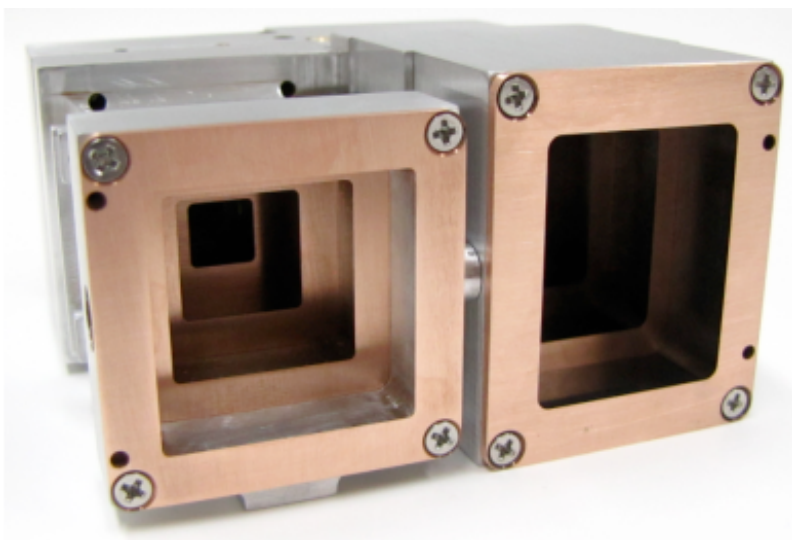
- **Utah St. U. & HISS (U. Maryland Eastern Shore)**
- **Neutral temperature profiles 90-140km**
 - ❑ **3U Boeing Colony cubesat provided by NRO**
 - ❑ **High resolution, hyper-spectral imaging spectrometer; Daytime airglow O2 760-770nm**
- **Project Started Sep 2013**

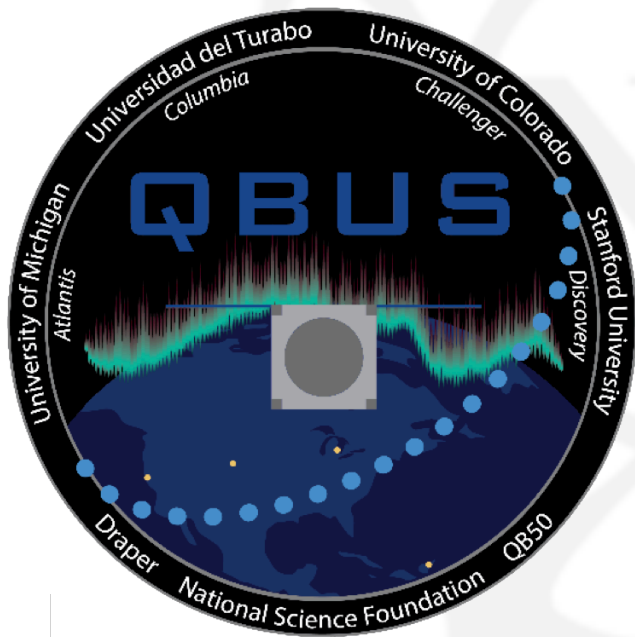






- **UCLA**
- **Pitch angle distribution of relativistic electrons and ions**
 - ❑ **3U cubesat; spinning @20rpm**
 - ❑ **Full angular distribution of electrons (50keV-5MeV) and ions (50-300keV); Magnetic field**
- **Project Started August 2014**
 - ❑ **Jointly funded with NASA**





- **Drapper Lab; U. Michigan; UC Boulder; Stanford U.; U. del Turabo**
- **Neutral temperature profiles 90-140km**
 - ❑ **3U Boeing Colony cubesat provided by NRO**
 - ❑ **High resolution, hyper-spectral imaging spectrometer; Daytime airglow O2 760-770nm**
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