Optical Communications for SmallSats and CubeSats
– or –
"Everything you always wanted to know about Small Enabling eXperiments*
*BUT WERE AFRAID TO ASK"

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With special thanks to T. Moretto, D. Klumpar, R. Fields, and INSPECT Team

And with special apologies to both David Ruben and Woody Allen

KISS Workshop, Monday, 11 July 2016

Motivation and Background

- The next decade poses great challenges but also promises great opportunities for new solar and space physics missions

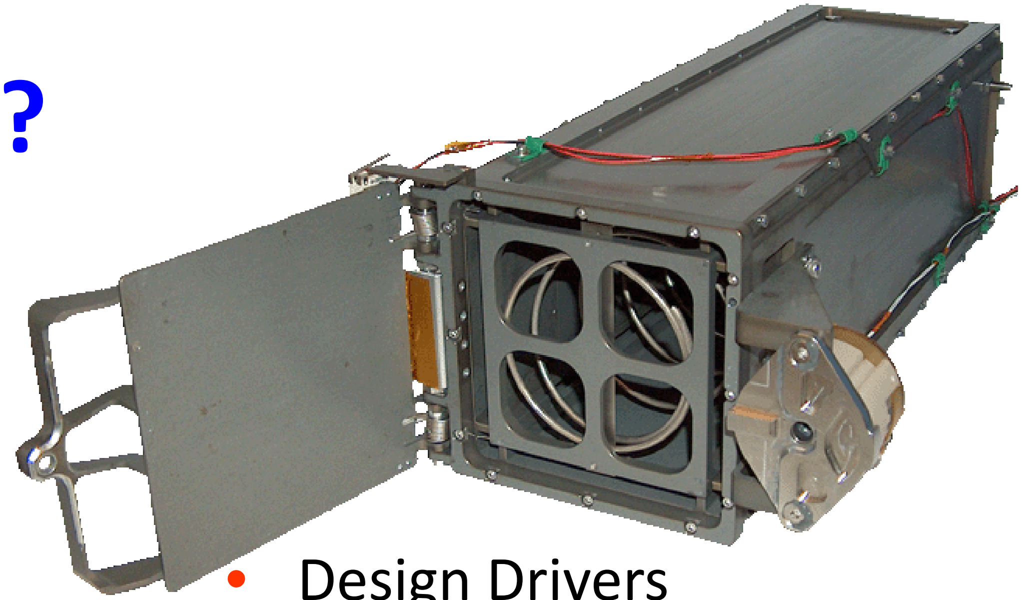
- As outlined in the 2012 Solar and Space Physics Decadal Survey, the prospects for new flagship or even large- and medium-coast space science missions in the coming decade are limited beyond the ones currently in development

- On the other hand, the Survey also points out the many intrinsic and indeed critical values of low cost missions, in which outstanding scientific discovery can be accomplished in targeted and important ways, with a timeliness and capacity for hands-on training of the next generation of space scientists and engineers (SmallSats and **CubeSats** – here, we focus on CubeSats)

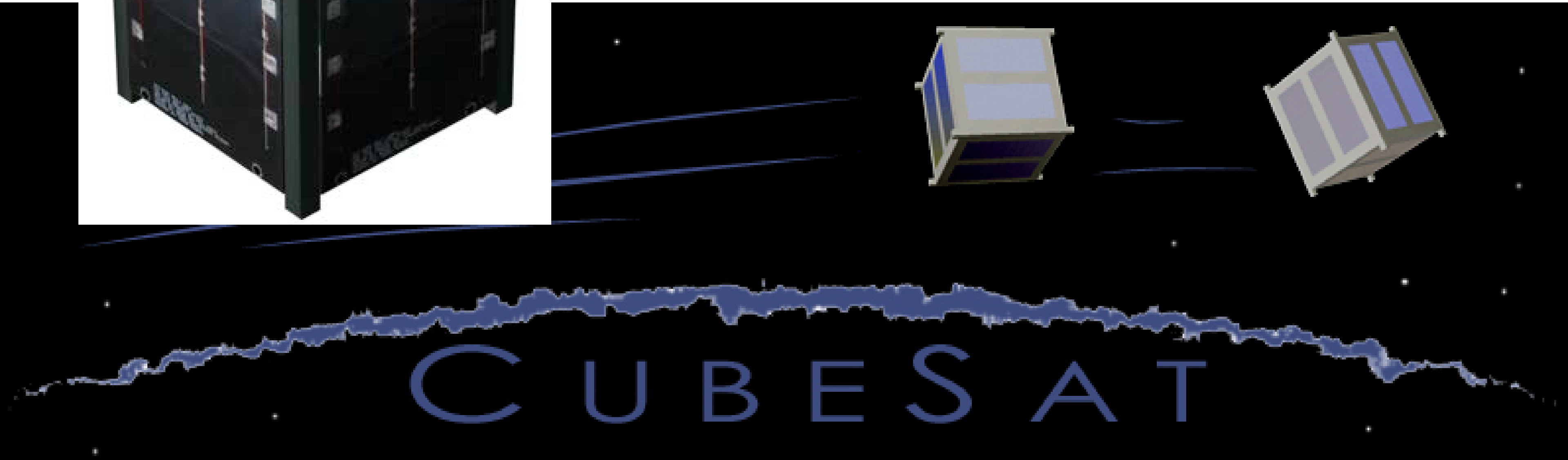
What is a CubeSat?

A pico-satellite Standard

1999 by Puig-Suari, CalPoly and Twiggs, Stanford

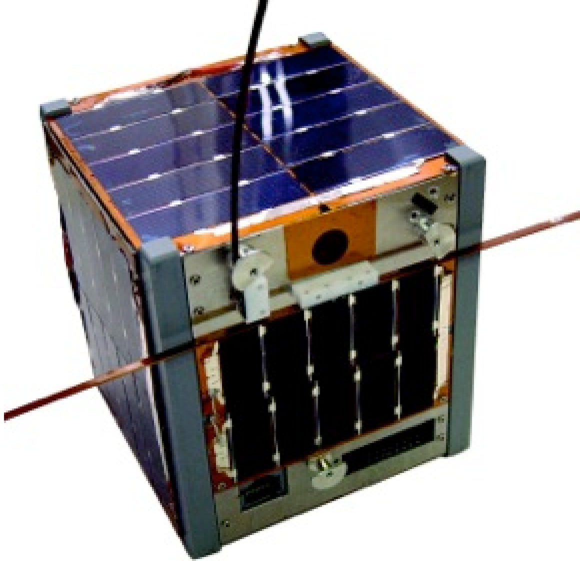


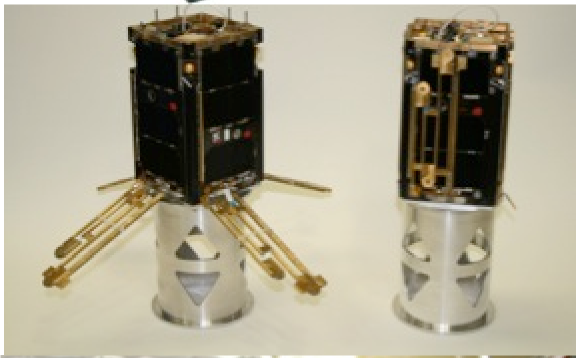
- Design Drivers
  - Simple and low-cost, but safe
  - Available COTs components
  - P-POD deployer system

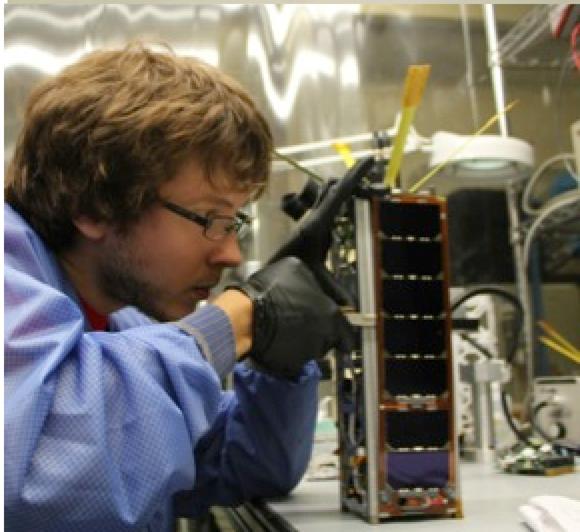


NSF Cubesat Program Since 2008

- **Geospace & atmospheric science and education run out of the Geospace Section of GEO/AGS at NSF (Therese Moretto)**
- **~2 new projects per year**
- **>80 unique missions proposed**
- **>12 projects funded**
- **Grants $900,000 total cost and 3 year duration**
- **NSF CubeSat program is demonstrating scientific value**







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

DICE
ASTRA
USU/SDL
Clemson
Embry Riddle

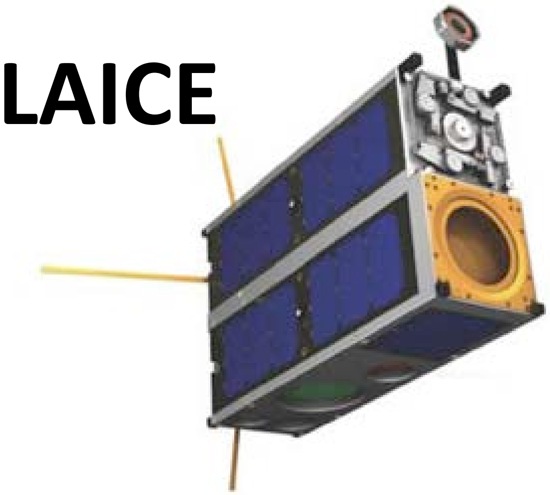
CADRE

ExoCube

CSSWE
Colorado Student Space Weather Experiment

CubeSat for Ions Neutrals Electrons and MAgnetic fields
trio cinema 3

LAICE



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FIREFLY

FIREBIRD
THE AEROSPACE CORPORATION
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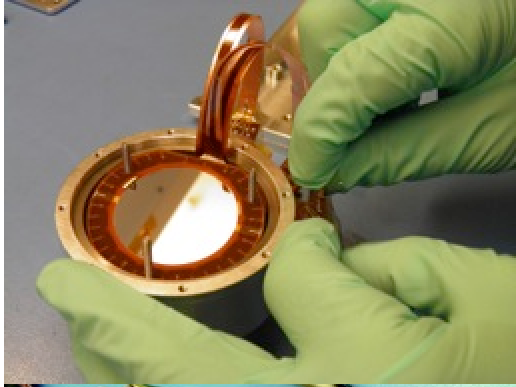
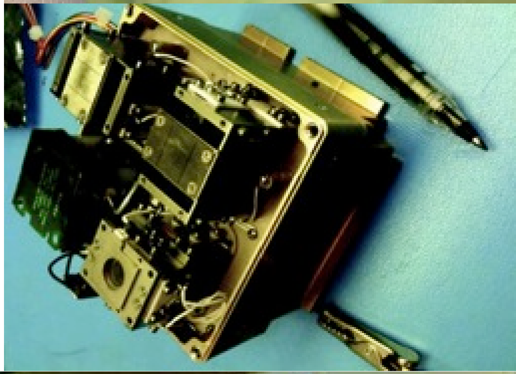
BOSTON UNIVERSITY
Focused Investigations of Relativistic Electron Burst Intensity, Range, and Dynamics

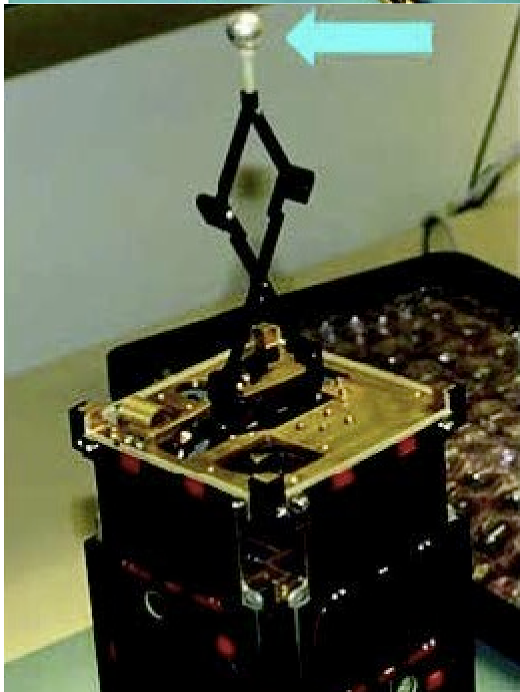
OPAL

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)







Science Summary of NSF FIREBIRD-I and -II Missions

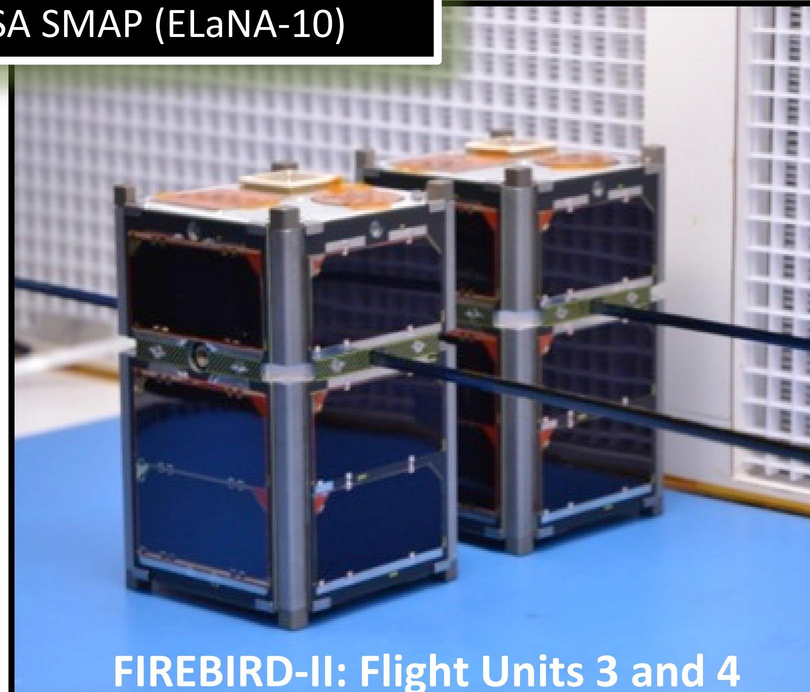
PIs: Harlan Spence (UNH) and David Klumpar (MSU)

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

FB-II Launched late 2015
VAFB Delta-II 7320 NASA SMAP (ELaNA-10)

FIREBIRD- I: Flight Units 1 and 2

Provided excellent science results;
FU1: 12/13 - 1/14, FU2: 4/14 – 9/14



FIREBIRD-II: Flight Units 3 and 4

Improved version of FB-I mission;
Launched and beautiful data since 1/2015

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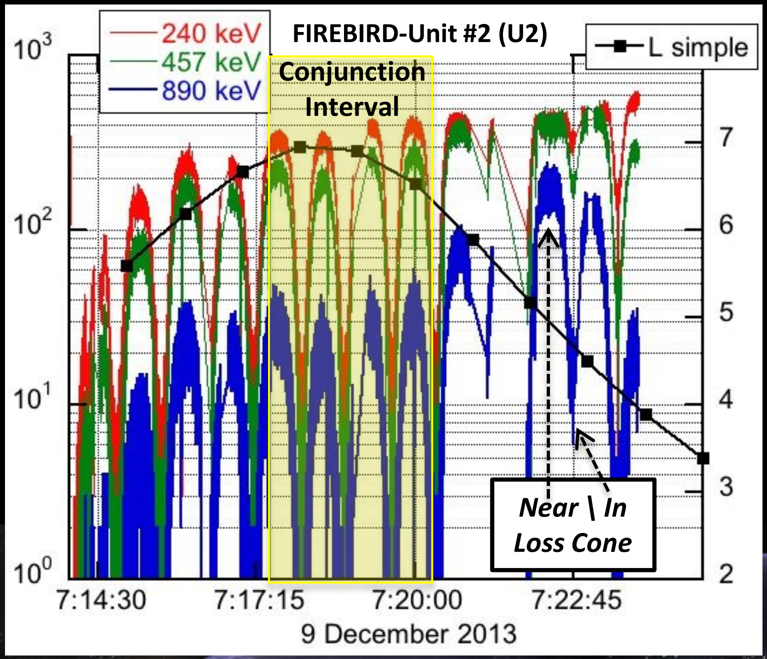
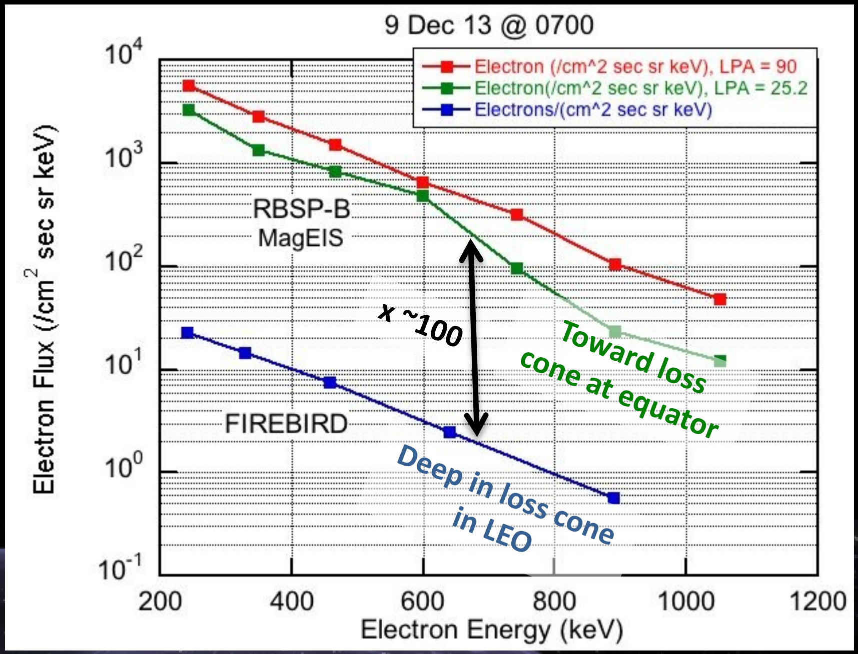
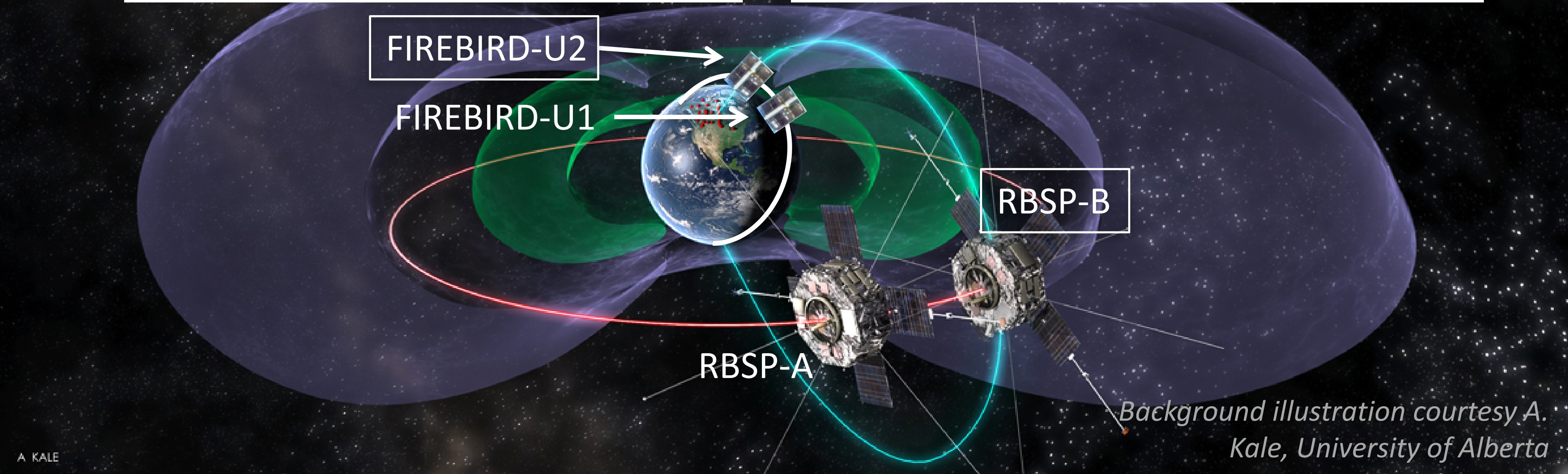
Comparison of Conjugate Spectral Shape and Electron Intensity (0.25 – 1 MeV) In/Near Loss Cone at LEO (FB-U2) & Equator (RBSP-B) at L ~ 6.5







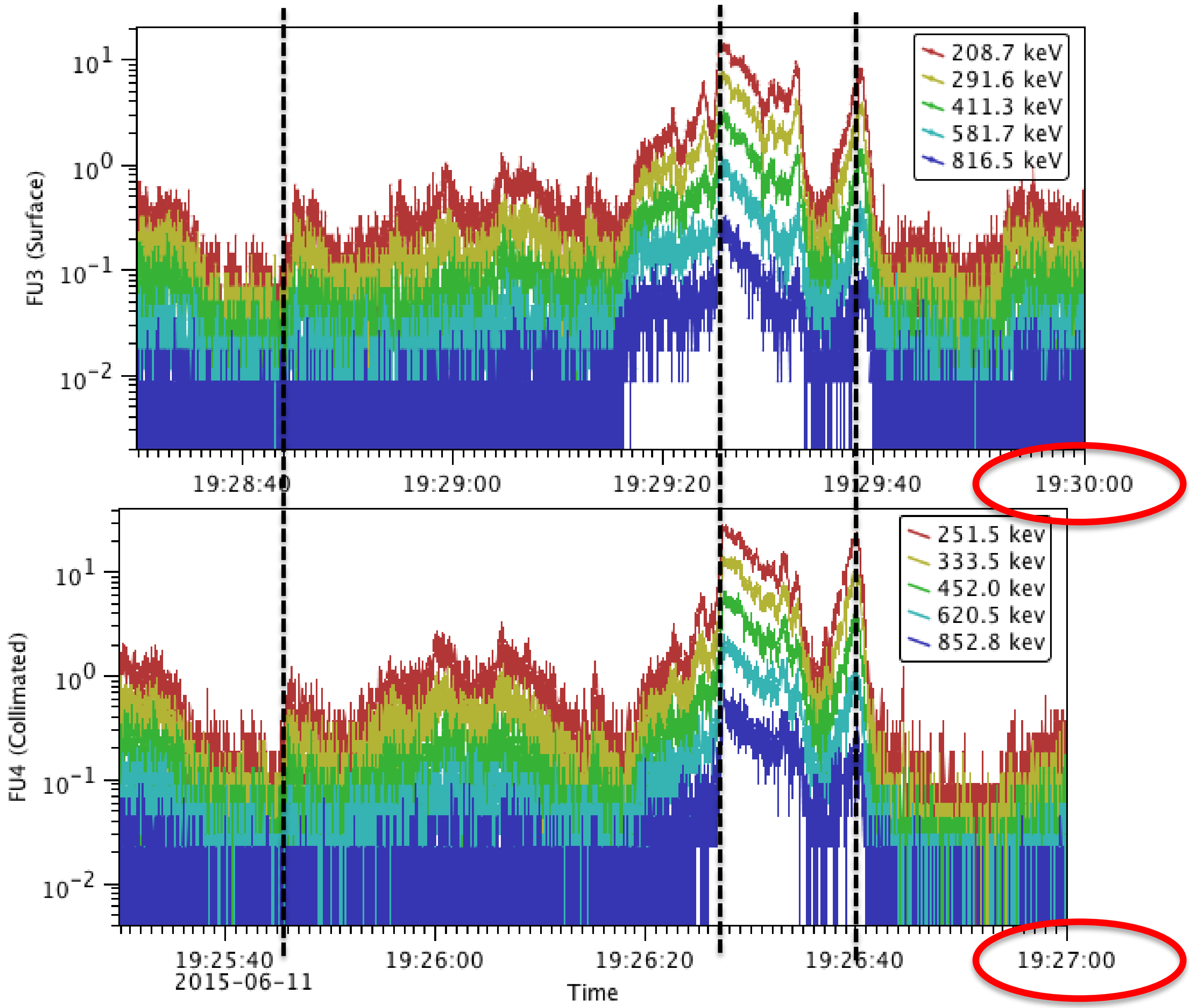
Background illustration courtesy A. Kale, University of Alberta

FIREBIRD-II Overview

- Follow-on FIREBIRD-II mission launched on 31 January 2015 from VAFB on SMAP launch (ELaNA-X) – STILL GOING STRONG!

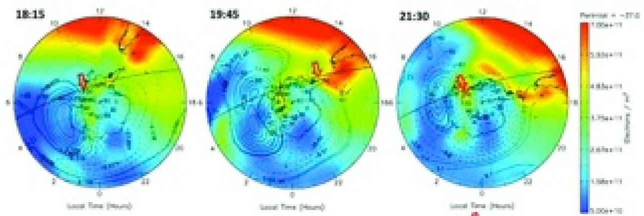
Top Rate Science – First unambiguous evidence of spatial structure in electron precipitation data

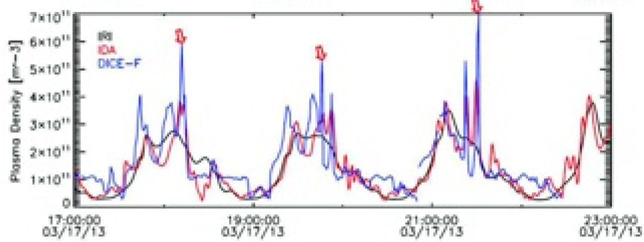
- Clear examples of temporally persisting (3 minutes) spatial bands of precipitation
- A single spacecraft would likely interpret structure as temporal
- Similar persistent enduring precipitation bands seen also by AC-6



CubeSat Status Report

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

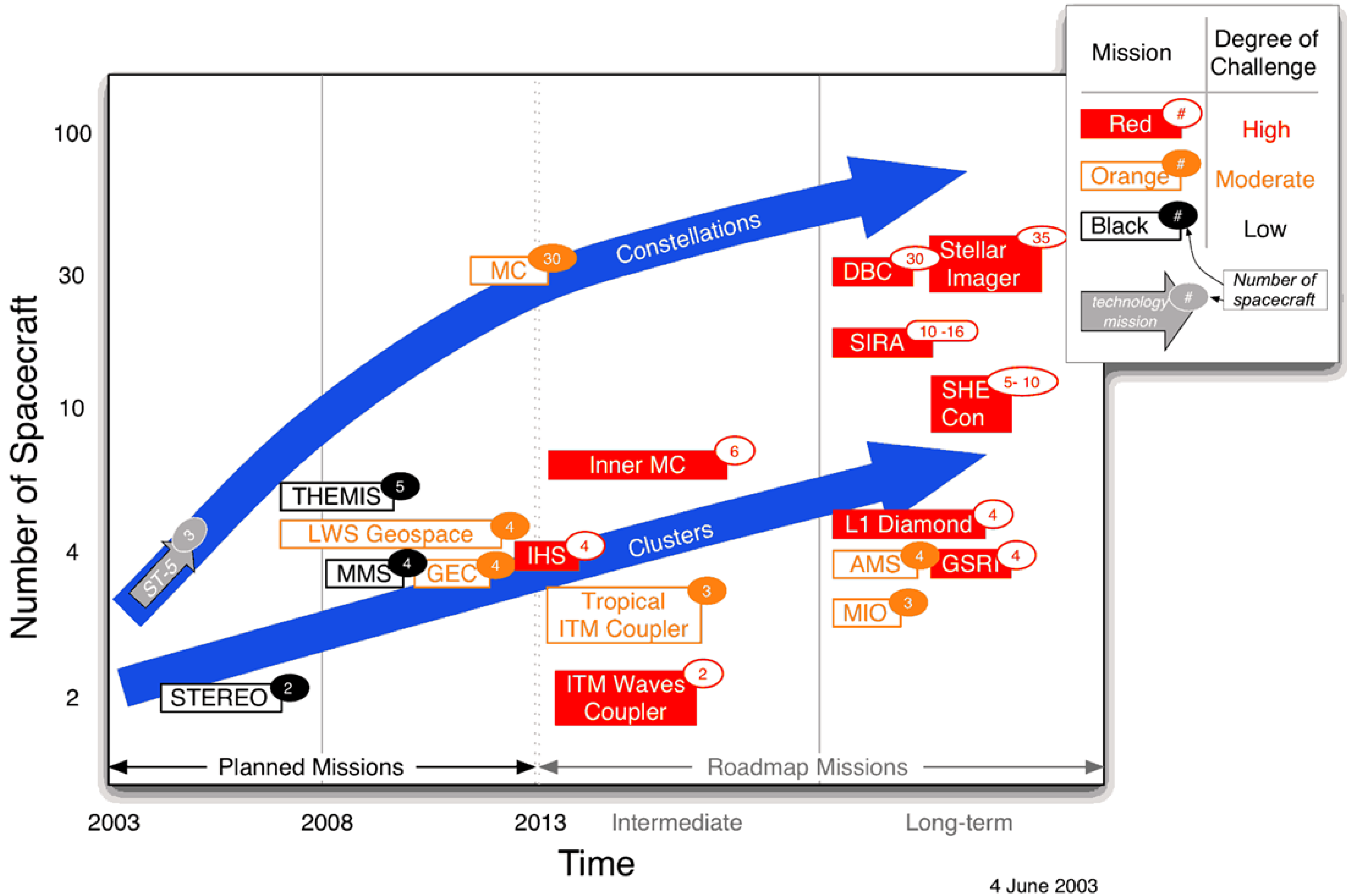




Cubesats in MEO and HEO

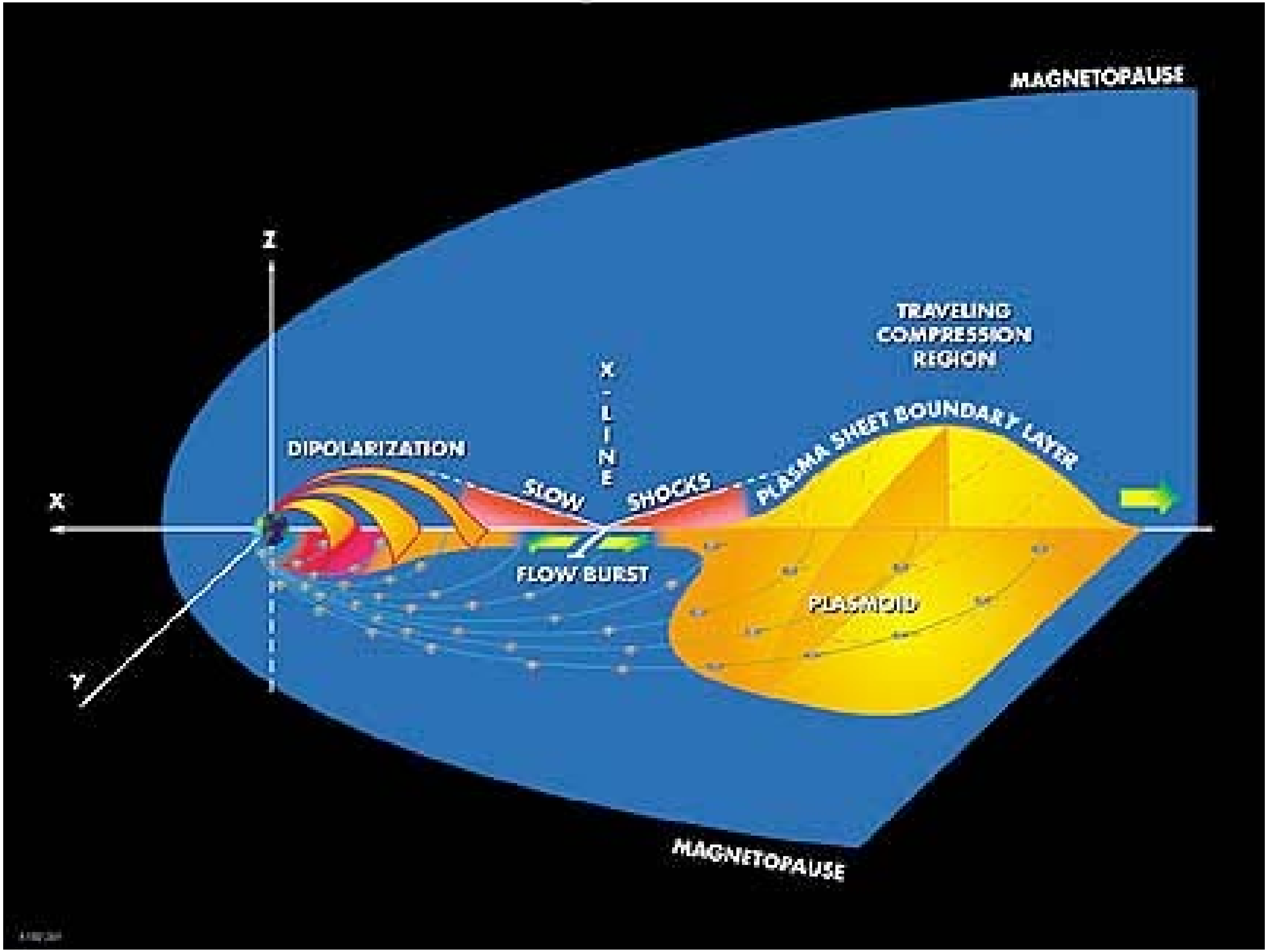
- Exciting potential
  - realize mag-con type missions and multi-point solar and solar wind monitoring; even planetary
- Main technical challenges include:
  - communication and power (related) – laser communication
  - radiation hardiness
  - maneuverability (propulsion and formation flying) – in-space propulsion

Priority Science Promotes Larger Numbers of Satellites Per Mission



The Challenge of "Economical" Spacecraft: *Develop affordable clusters and constellations of spacecraft for multi-point measurements of the connected Sun-Earth System.*

Magnetospheric Constellation – CubeSat Implementation?



Cubesats Beyond Earth…?

- **Many heliophysics (and planetary) mission concepts could be done today using smallsats/CubeSats, however virtually all are limited by communication concerns**
- **One example - *INSPECT (Interplanetary Neutron and Solar Particle Event CubesaT)* proposed to NASA by team including UNH (Spence), The Aerospace Corporation (Fields), and MSU (Klumpar)**
  - **Mission of opportunity for CubeSat mission to interplanetary space particle environment – Decadal Survey-class science**
  - **Laser communication identified as an enabling technology – compelling case made yet…**
  - **NASA review panel skiddish about technical readiness/risk – underscores importance of this KISS workshop!**

Summary and Conclusions

- While such small missions as described today will not likely ever replace the larger strategic missions, in the coming decade they will certainly provide fresh, vibrant opportunities for innovative approaches on PI-led missions

- These missions would stand alone scientifically as well as complement, augment, and provide continuity and community engagement and opportunity between the larger strategic missions that demand more resources.

- The community should continue to develop these innovative approaches, and the funding agencies should continue to grow a funding wedge to support them, including further development of laser communication technology!

Those who assert that "It cannot be done", should never interrupt those who are already doing it.

(Segue to Renny Fields!)