Small Satellite Constellations for Geospace Sciences

Harlan E. Spence

University of New Hampshire
Institute for the Study of Earth, Oceans, and Space

With special thanks to T. Moretto and D. Klumpar

And also credits to FIREBIRD and MagCon Teams

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A33P-04; Moscone West 2011

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
  - In space science many science questions require clusters, swarms or even dense constellations of measurements

Overview

- In this presentation, we provide examples of such missions that have recently or are currently making new space science discoveries in targeted areas on small and less costly platforms that those from the larger more costly, community-consensus missions (e.g., NASA's LWS missions, STP missions, etc.)

- We also outline examples of new sensor designs and technologies that lend themselves to such resource-limited platforms, as well as examples of missions that are made possible that could answer long-standing and key space science questions.

- Finally we note several exciting enabling technologies with the potential to substantially improve or even transform small, low-cost mission capabilities

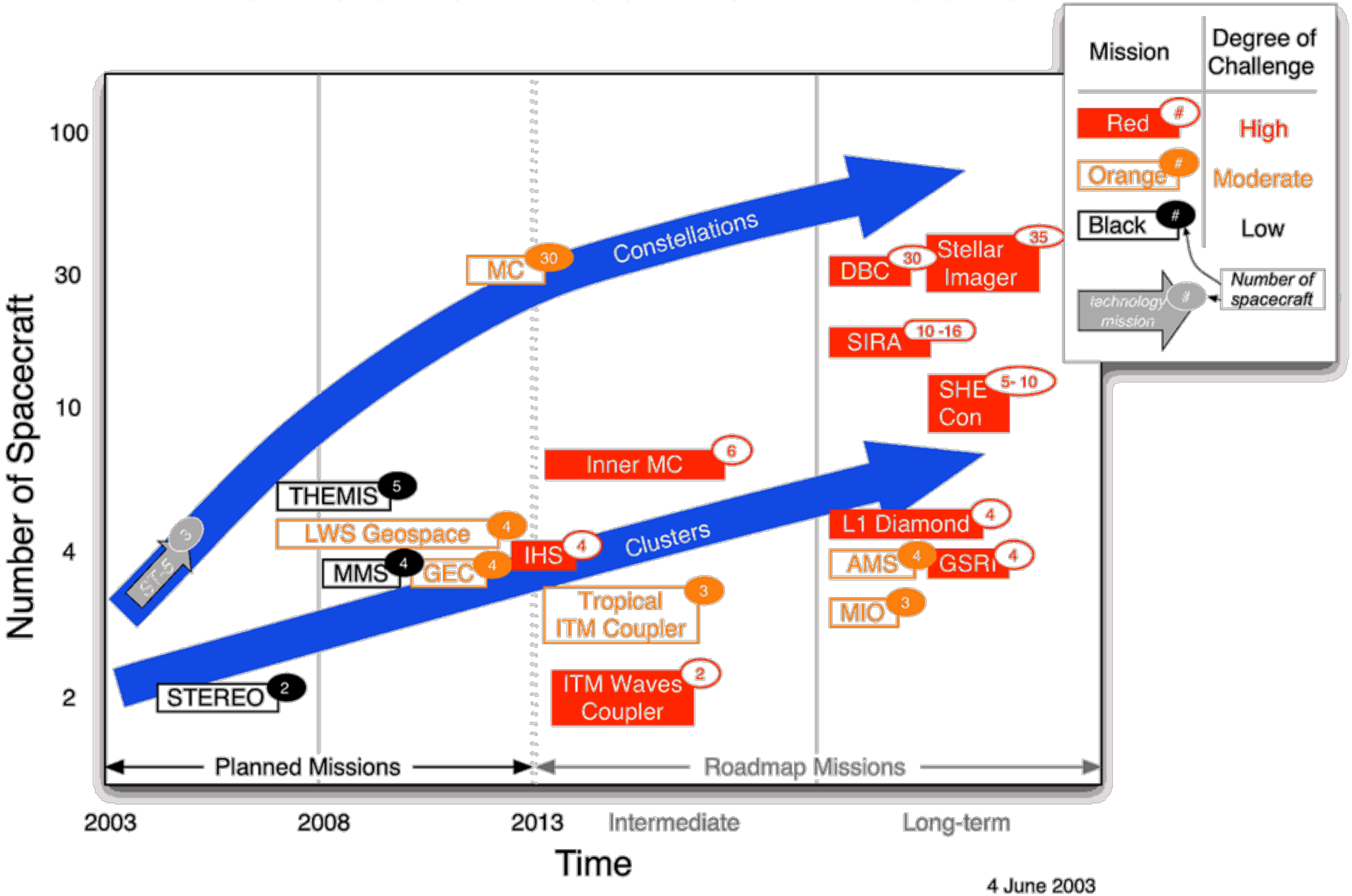
Larger Numbers of Satellites Per Mission Promotes Small Satellite Capability

- Science-drivers have existed for decades for smaller, less-costly satellites; a community benefit of going toward smaller spacecraft means more students can be more meaningfully involved in a same what that they have been in the rocket and balloon programs

- NASA ran community workshops in the 1990's that explored new missions needing multiple spacecraft to achieve our science goals – these led to both large flagship missions (NASA Cluster/MMS) and medium sized PI-led missions (NASA THEMIS)

- But it was clear that other science questions could be tackled with clusters, swarms, or constellations of microsats, nanosats, and picosats (what we now refer to more commonly as CubeSats)

Priority Science Promotes Larger Numbers of Satellites Per Mission

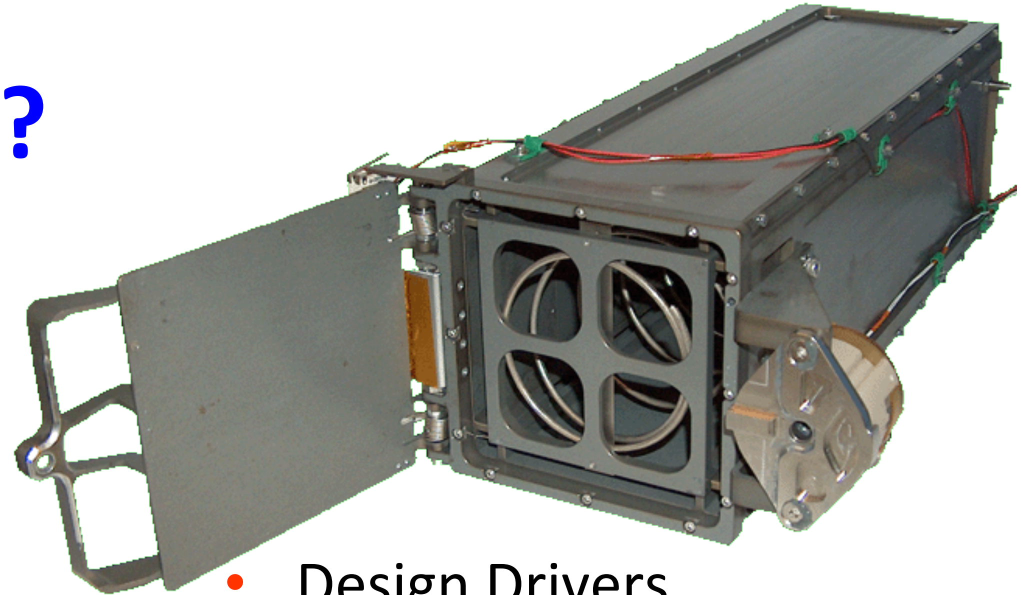


The Challenge of "Economical" Spacecraft: *Develop affordable clusters and constellations of spacecraft for multi-point measurements of the connected Sun-Earth System.*

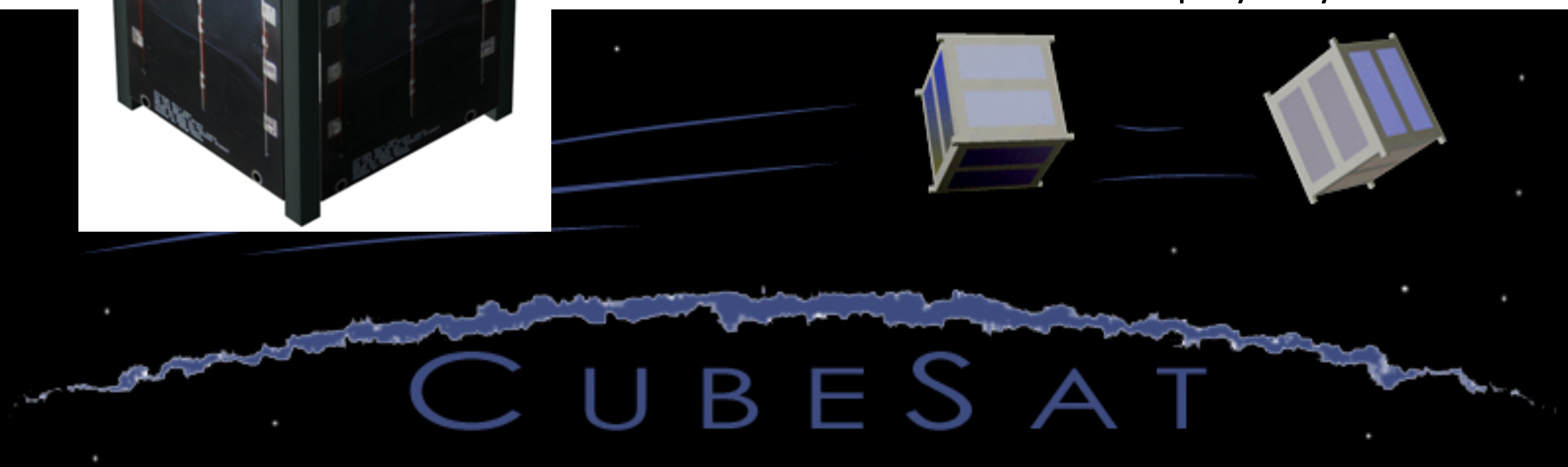
What is a CubeSat?

A pico-satellite Standard

1999 by Puig-Suari, CalPoly and Twiggs, Stanford

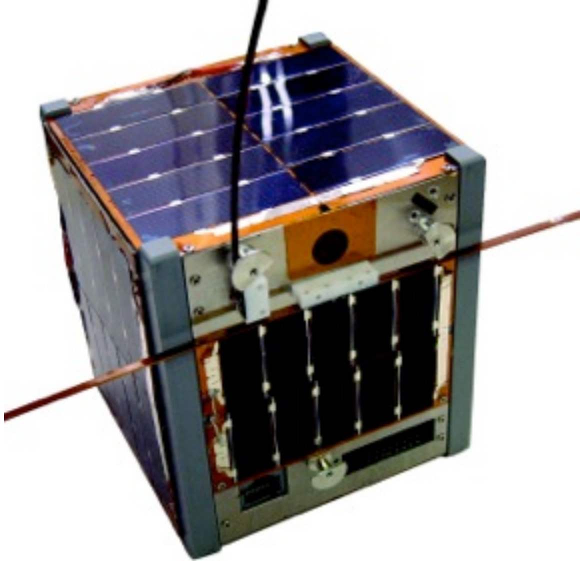


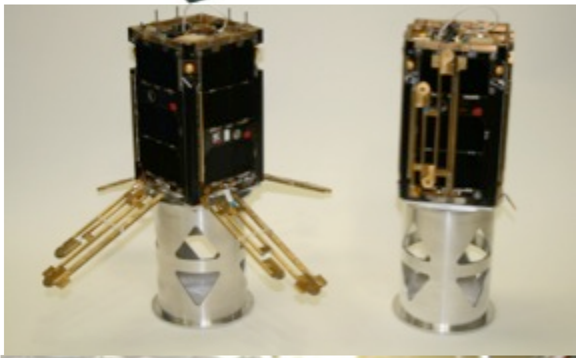
- Design Drivers
  - Simple and low-cost, but safe
  - Available COTs components
  - P-POD deployer system

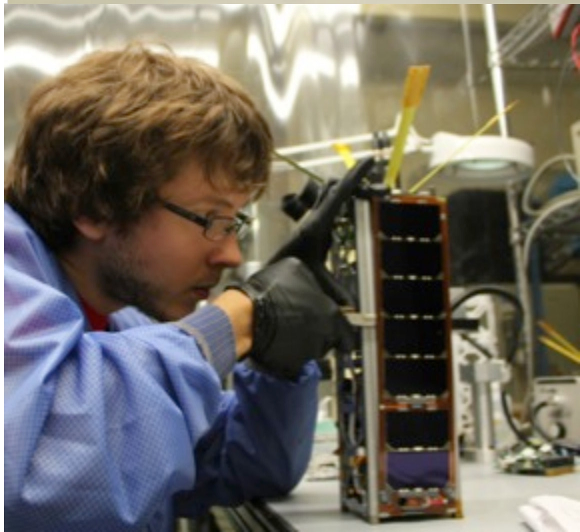


NSF CubeSat Program Since 2008

- **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**







Science Summary of NSF FIREBIRD-I and -II Missions

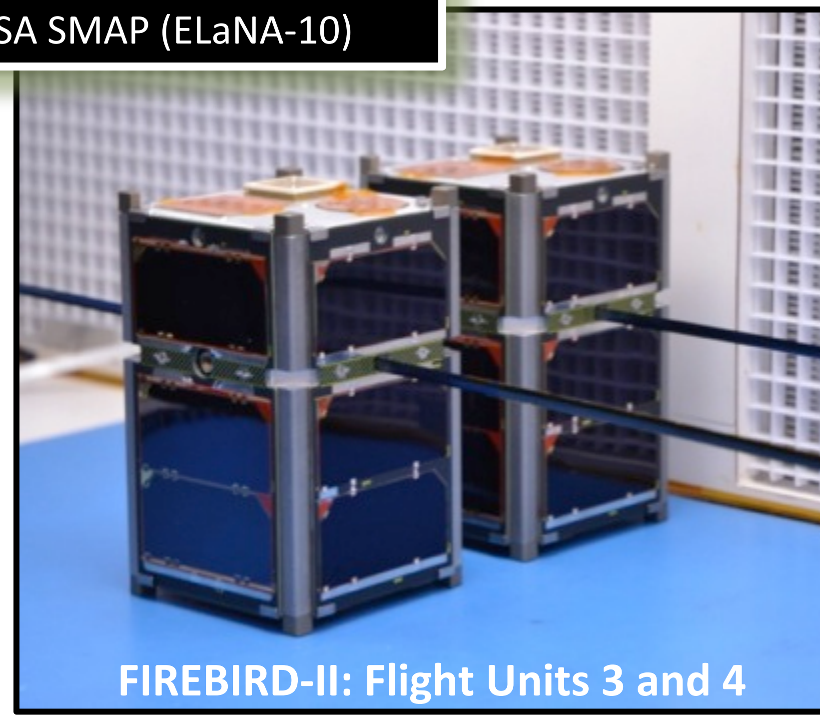
PIs: Harlan Spence (UNH) and David Klumpar (MSU)

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

FB-II Launched: Jan 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 in January 2015 and still going!

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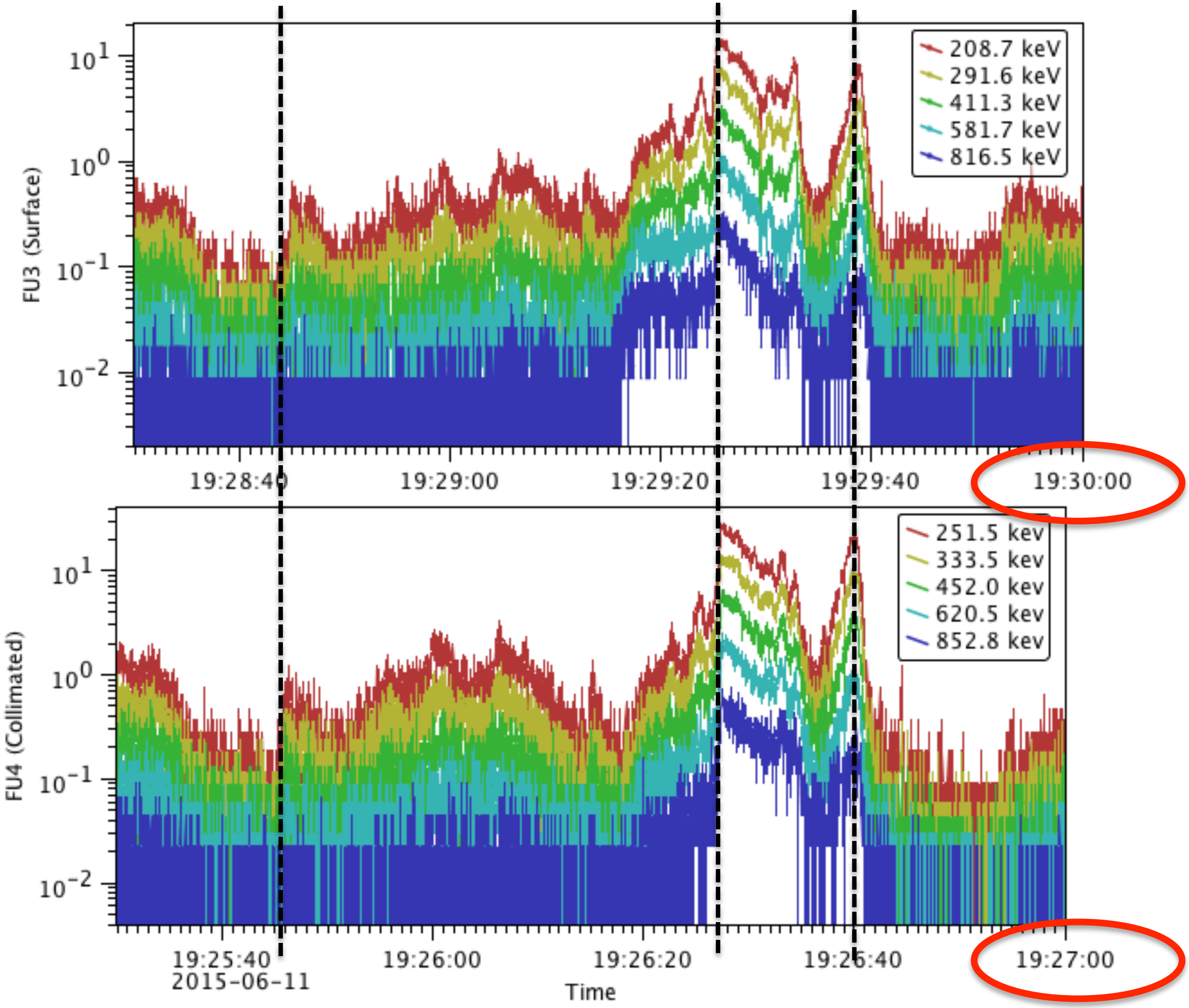
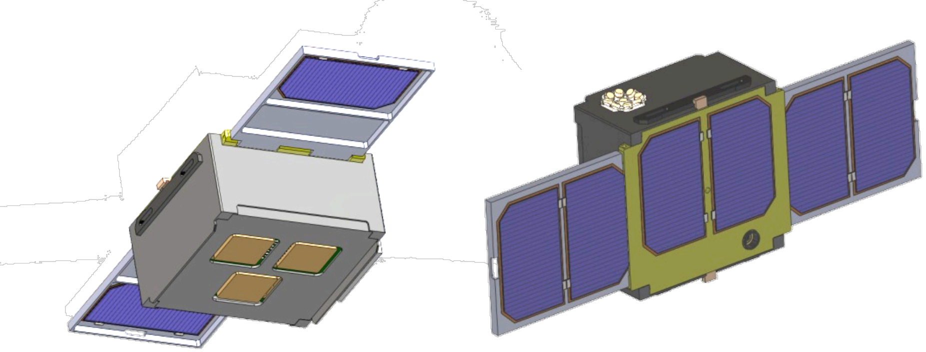
Almost purely spatial structure seen in electron HiRes FIREBIRD-II FU3/FU4 precipitation data

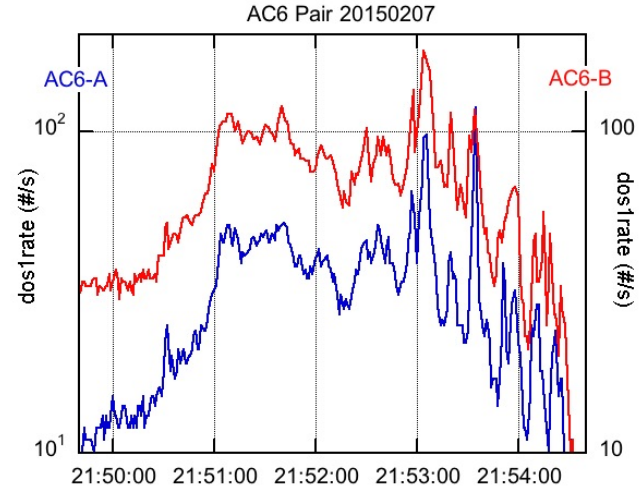
- Clear examples of temporally persisting (3 minutes) spatial bands of precipitation
- A single spacecraft would likely interpret structure as temporal
- Similar persistent enduring precipitation bands seen also by AC-6
- Same as "curtains" presented by Bern Blake – FB s/c are more widely separated and so curtains persist at least 3 minutes…



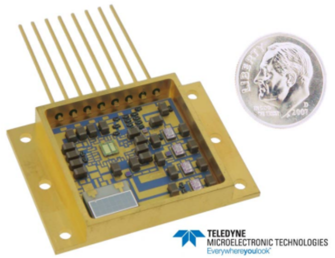
AeroCube-6



- AeroCube-6 is two 0.5U CubeSats.
- Science goal: measure spatial scales of radiation in LEO.
- Launched: 19 June 2014 aboard Dnepr.
- Orbit: 620 x 700 km x 98 deg.
- Payload: 3 dosimeters on each satellite.
  – Including 3 new variants that have never flown before.
- Nominal sample rate is 1 Hz.
  – Dosimeters A1 and B1 can burst at 10 Hz.
- Using differential drag to control spacecraft in-track separation.

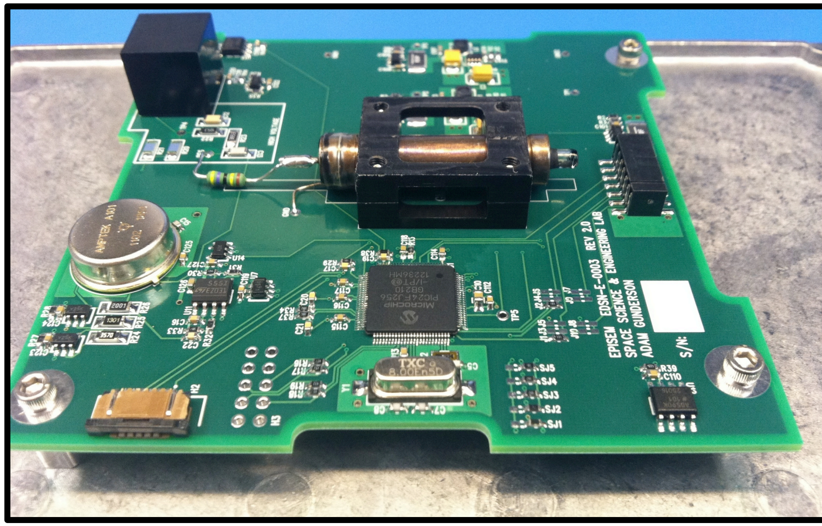


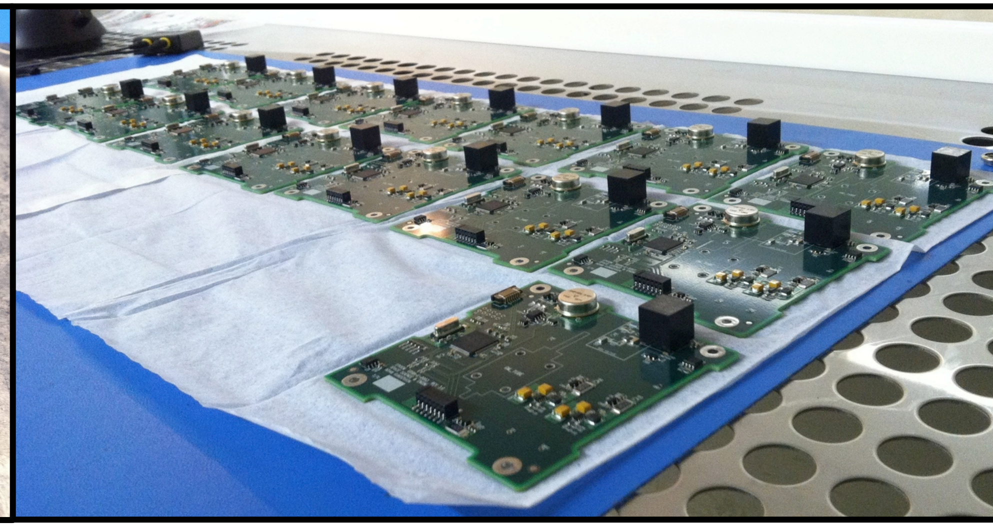
Dosimeter Payload:

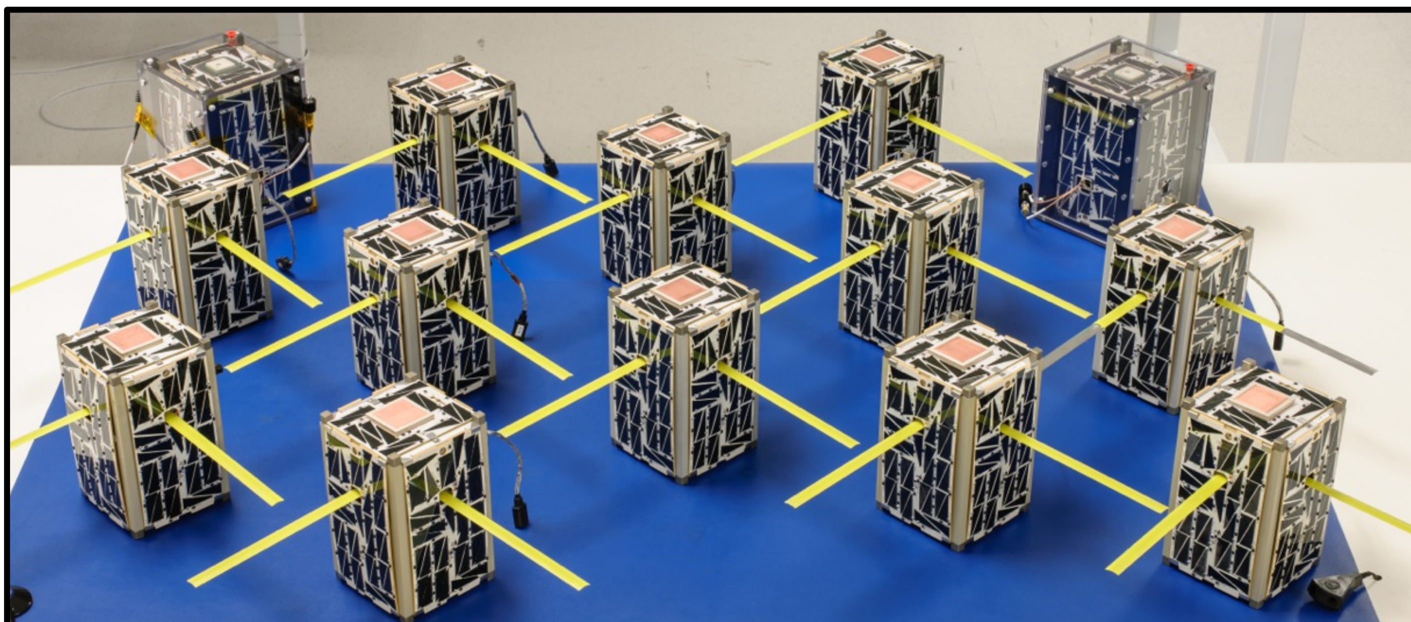


S/C	ID#	Dosimeter	Measures
A	1	Thin Window Low LET Variant	>50 keV electrons & >600 keV protons
A	2	Thin Window High LET Variant	>600 keV protons
A	3	Standard Teledyne	>1 MeV electrons & >10 MeV protons
B	1	Thin Window Low LET Variant	>50 keV electrons & >600 keV protons
B	2	Thin Window High LET Variant	>600 keV protons
B	3	High LET Variant	>10 MeV protons

The EDSN/NODES CubeSats



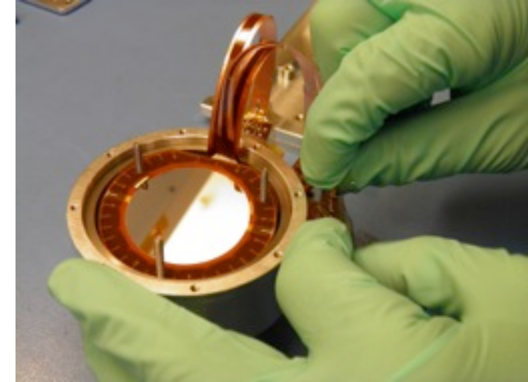


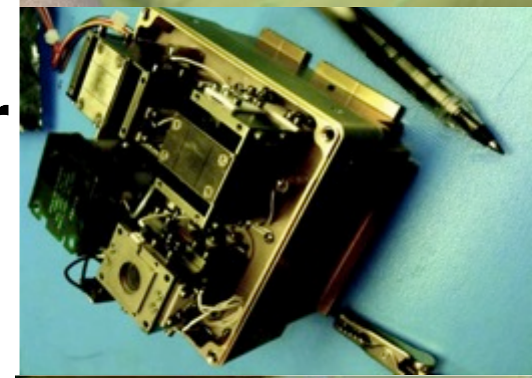


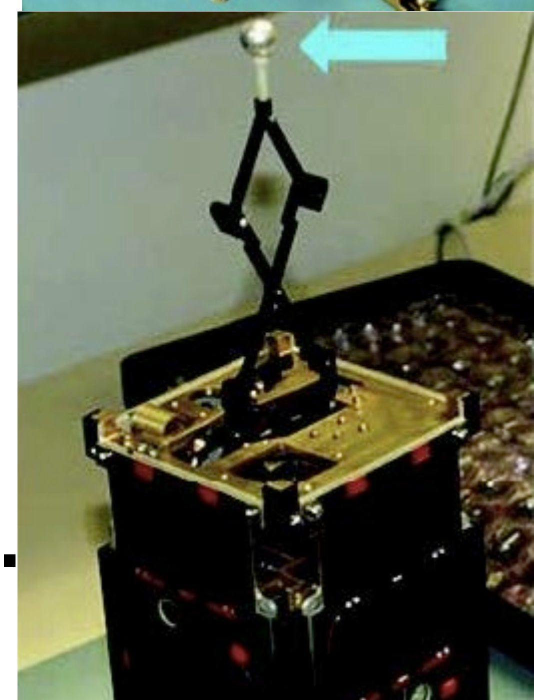
Energetic
Particle
Integrating
Space
Environment
Monitor

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)**



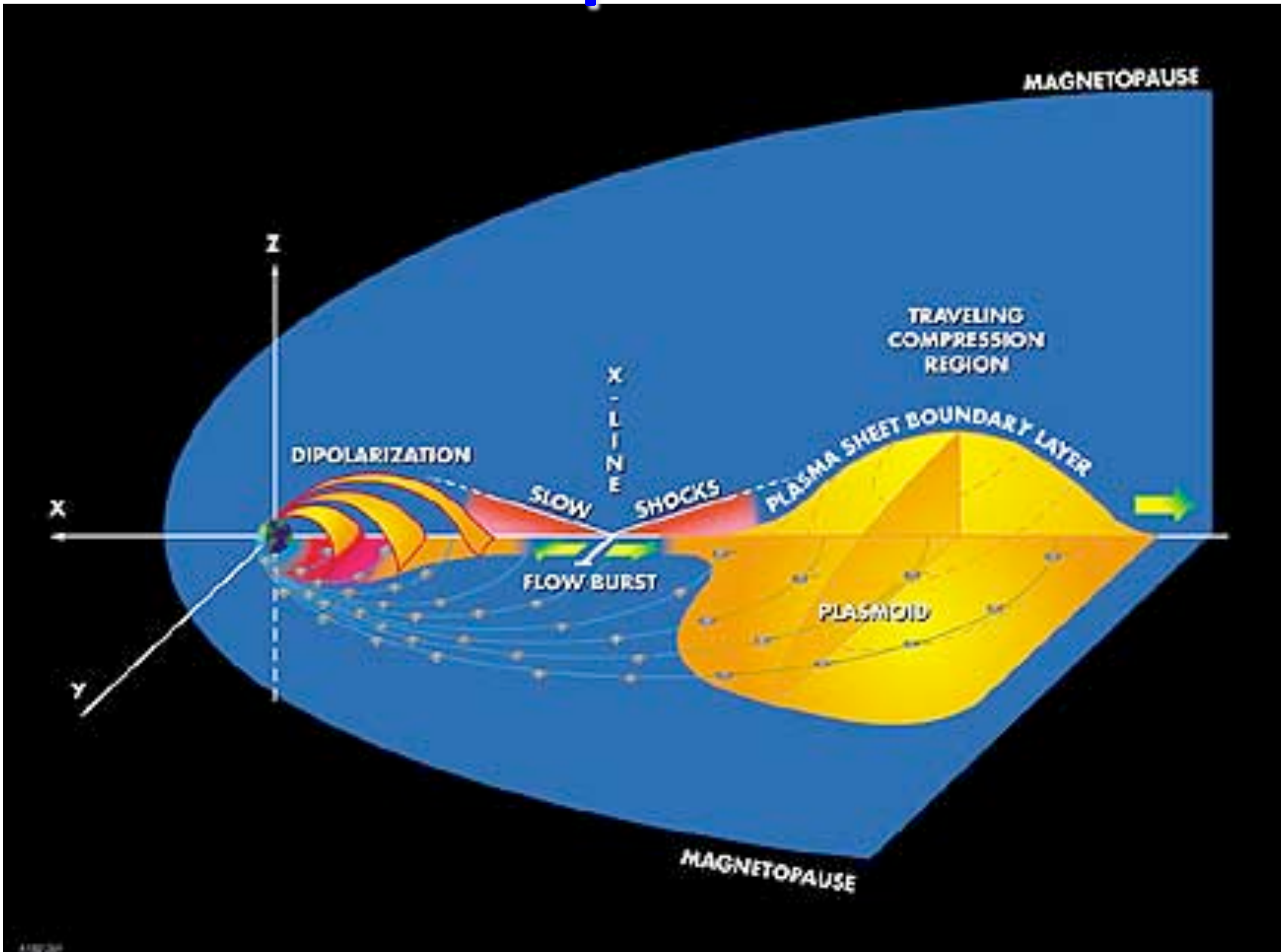


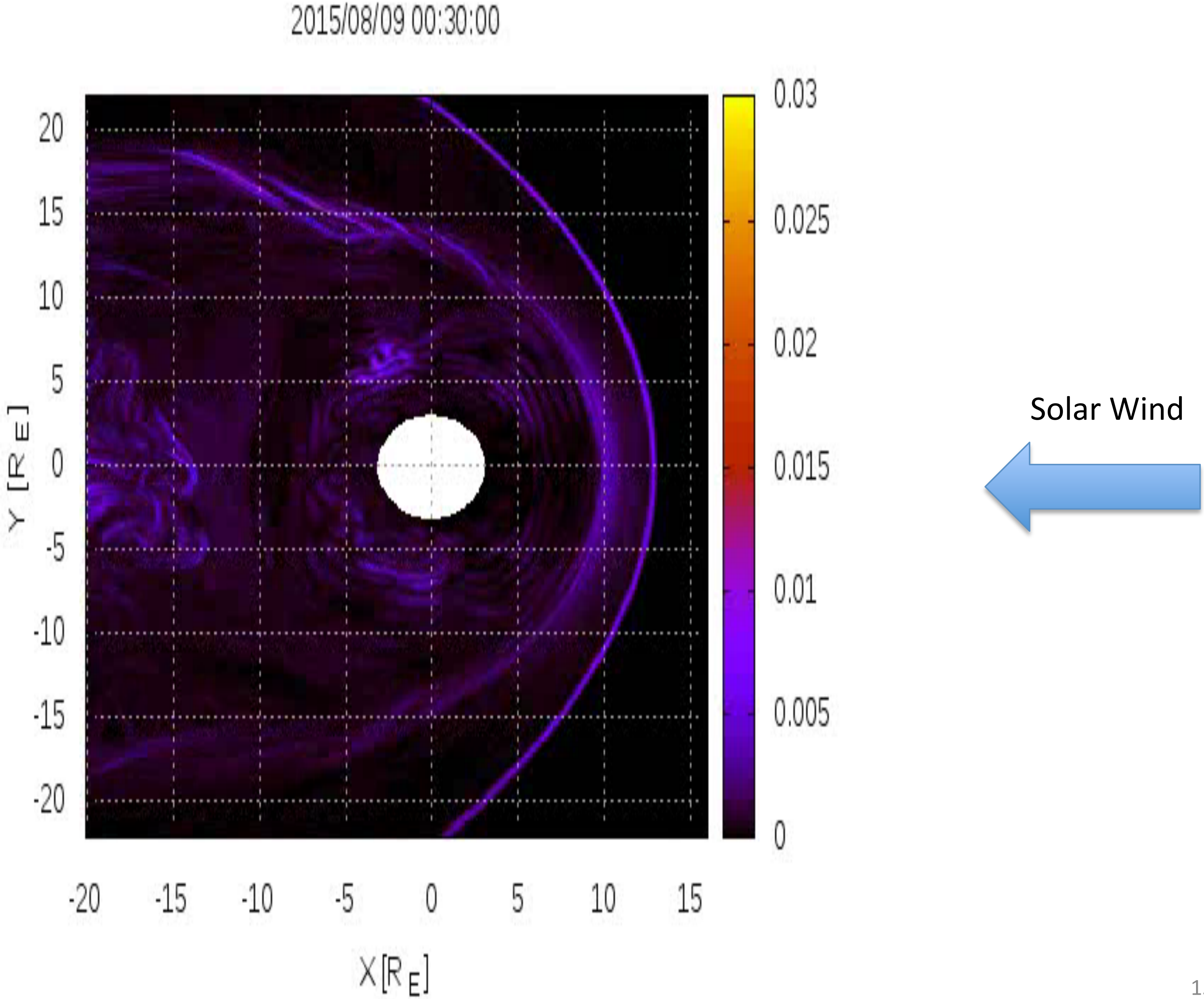


Cubesats in HEO & Beyond

- 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) – optical/laser communication (KISS Workshop ongoing)
  - radiation hardiness
  - maneuverability (propulsion and formation flying) – in-space propulsion

Magnetospheric Constellation – CubeSat Implementation?

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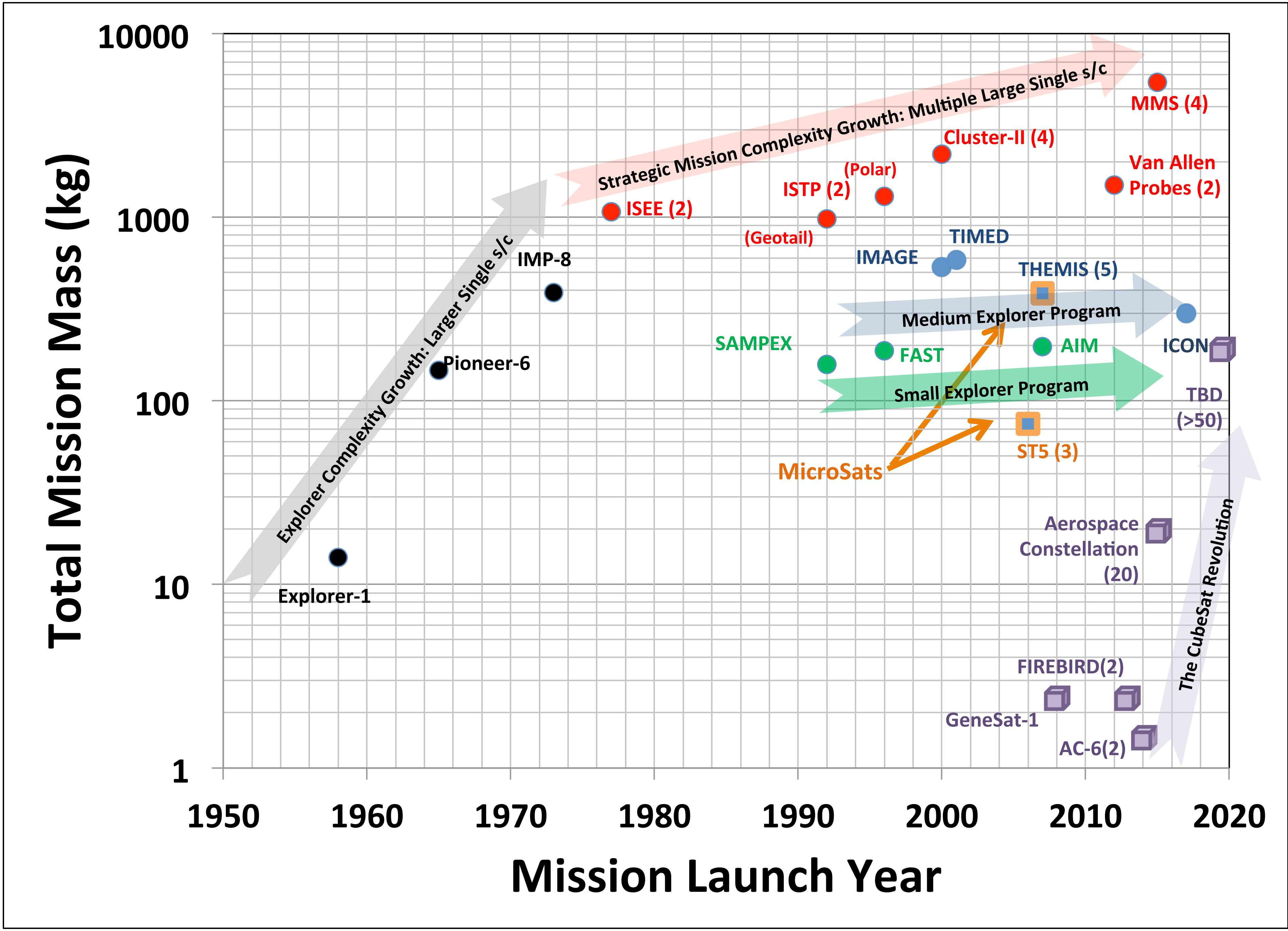
Solar Wind



Total Mission Mass (kg)
10000
1000
100
10
1
Mission Launch Year
1950
1960
1970
1980
1990
2000
2010
2020
Explorer Complexity Growth: Larger Single s/c
Strategic Mission Complexity Growth: Multiple Large Single s/c
Explorer-1
Pioneer-6
IMP-8
ISEE (2)
ISTP (2)
(Polar)
(Geotail)
Cluster-II (4)
MMS (4)
Van Allen
Probes (2)
TIMED
IMAGE
THEMIS (5)
Medium Explorer Program
ICON
SAMPEX
FAST
AIM
Small Explorer Program
TBD
(>50)
ST5 (3)
MicroSats
Aerospace
Constellation
(20)
The CubeSat Revolution
FIREBIRD(2)
GeneSat-1
AC-6(2)

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, particularly requiring multisatellites

- 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 the key enabling technologies such as optical communication!