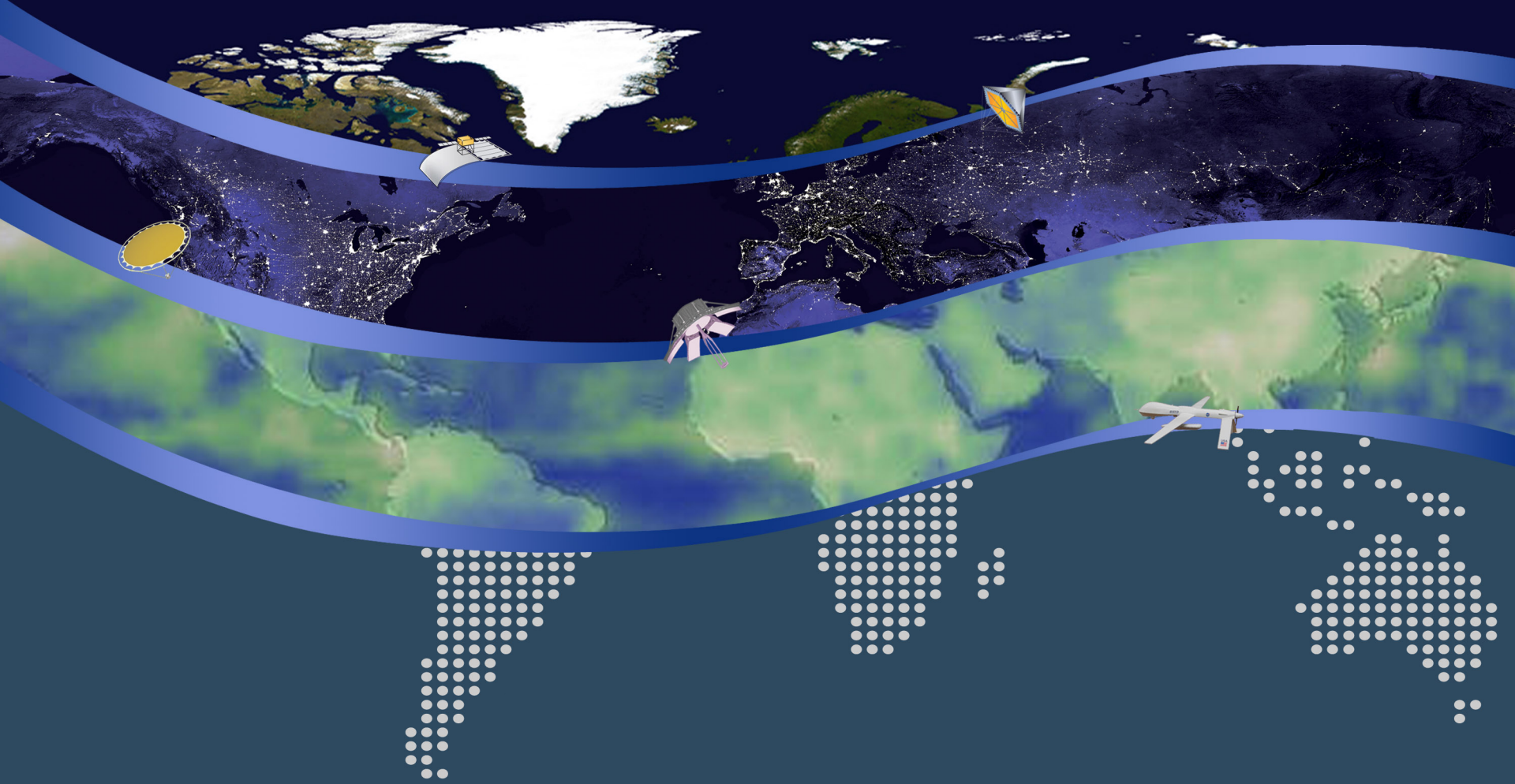


Spaceborne Flight Validation of NASA ESTO Technologies: HyspIRI IPM

August, 2011

Dr. Charles D. Norton

NASA Earth Science Technology Office and

Jet Propulsion Laboratory, California Institute of Technology

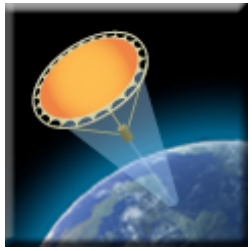
Earth Science Technology:
Overview and Program Elements

The Earth Science Technology Office (ESTO) is a ***targeted, science-driven, competed, actively managed, and dynamically communicated technology program*** and serves as a model for technology development.

Competitive, peer-reviewed proposals enable selection of best-of-class technology investments that ***retire risk*** before major dollars are invested: a cost-effective approach to technology development and validation.

ESTO investment elements include:

Observation Technologies:



Instrument Incubator Program (IIP)
provides robust new instruments and measurement techniques

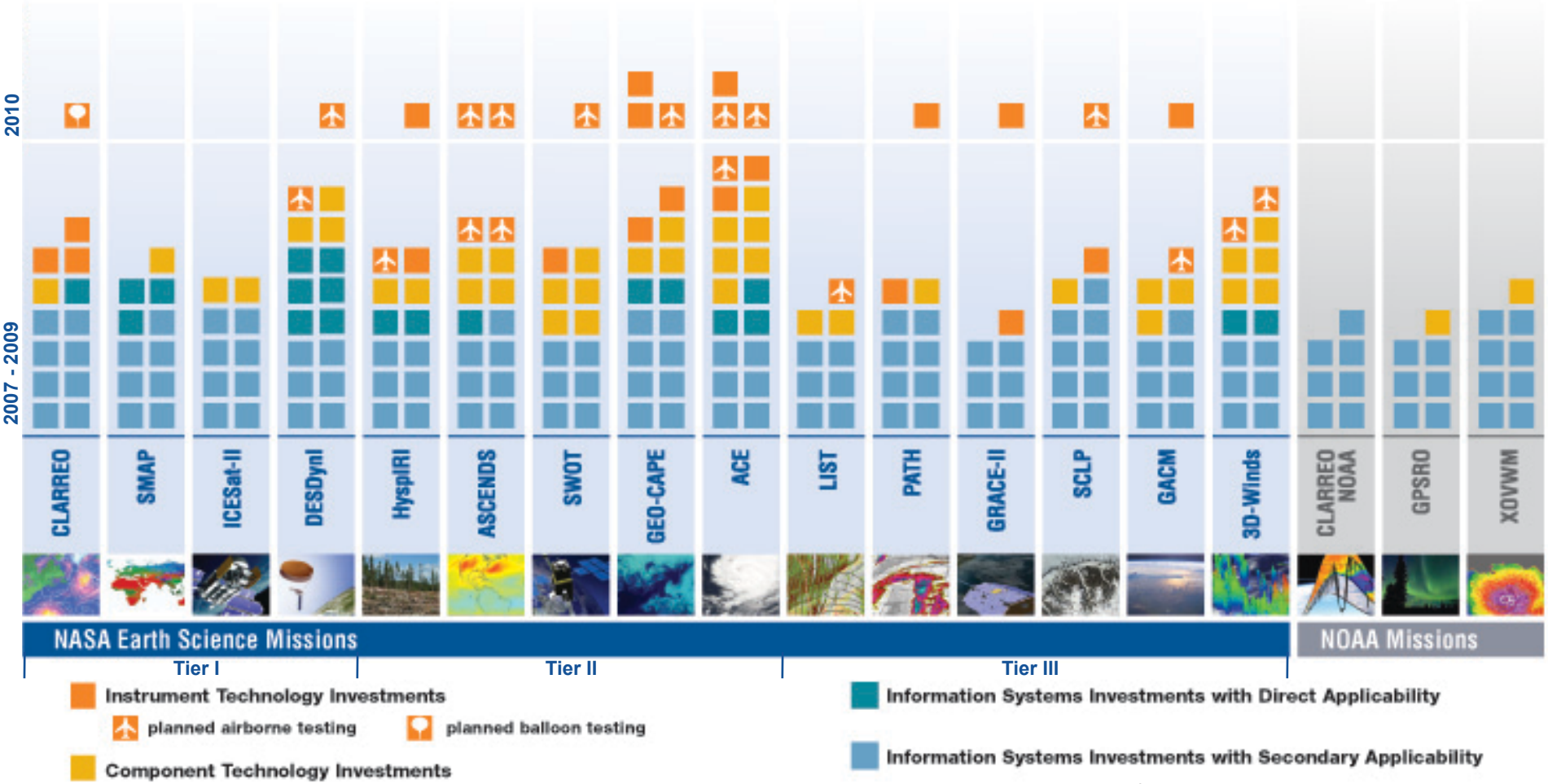
Advanced Component Technologies (ACT)
provides development of critical component and subsystem technologies for instruments and platforms

Information Technologies:

Advanced Information Systems Technology (AIST)
provides innovative on-orbit and ground capabilities for communication, processing, and management of remotely sensed data and the efficient generation of data products and knowledge

Earth Science Technology:
New Investments Enabling the Decadal Survey

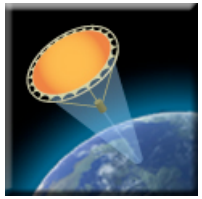
Upon publication of the Earth Science Decadal Survey in 2007, ESTO investments **already supported all 18 of the recommended mission concepts**. Since then, ESTO has awarded **73** additional technology projects representing an investment of ***over $172M directly related to the Earth Science priorities outlined by the Decadal Survey.***



Earth Science Technology:
Incremental TRL Advancement Strategy

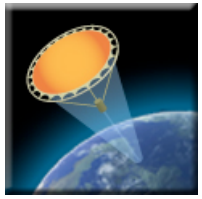
Current ESTO program lines generally advance technologies to TRL-6: System/ subsystem prototype demonstration in the relevant environment (ground or space)

ESTO now seeks to develop a new program line to **flight qualify** technologies through successful spaceborne demonstrations to TRL-8/9



Concept Formulation — Component Demo (Relevant Environment)

Advanced Component Technology (ACT)
TRL 2 - 5



Characteristic Proof of Concept — (Sub)-System Prototype Demo (Operational Environment)

Instrument Incubator Program (IIP)
TRL 3 - 6

Concept Formulation — System Prototype Demo (Operational Environment)

Advanced Information Systems Technology (AIST)
TRL 2 - 7

Component Demo (Lab Environment) — Flight Qualified

Technology Flight Validation (ATI)
TRL 4 – 8/9

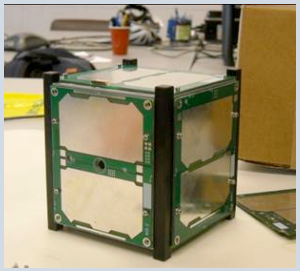
TRLs defined by NASA Procedural Requirements 7120.8 (Exp. Feb., 2013)

Technology Space Flight Validation

- Non-validated technology is generally acknowledged as a primary cause of NASA and DoD mission delays and cost overruns. For SMD, instrument development problems occur in > 60% of all missions, leading to cost and schedule delays.
- We propose a nimble, competitive program which takes advantage of recent advances in alternative opportunities to access space to retire risk and validate technologies. (*No requirement for science data campaign).*
- ESTO was requested to put some "skin in the game" to demonstrate this capability.

Onboard Processing – Two orders of magnitude data reduction for the Multiangle Spectro-Polarimetric Imager (MSPI)

Realtime Onboard Processing for MSPI (AIST)

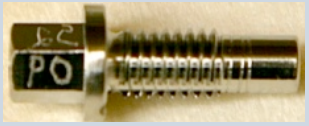


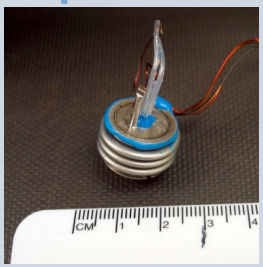
CubeSat Flight Validation (U Michigan/JPL) MRR 6/11

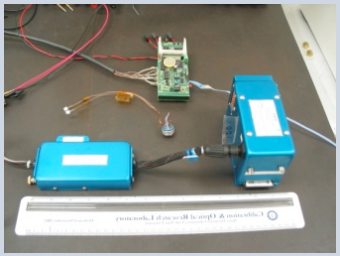
Launch on NPP

Phase Change Temperature Calibration - Black Body Calibration to 0.01K for Radiance Measurements

Phase Change Cells from Utah State and Wisconsin (IIP)







Flight Housing with Utah State Cell

Launch to ISS in 2011 & 2012

Flight Validation Drivers

Increased number of flight opportunities for secondary payloads

- NASA Launch Services' CubeSat Launch Initiative (CLI) Program also known as Educational Launch of Nano-Satellites (ELaNa)
- DOD Space Evaluation Research Board (SERB)
- US Government Rideshare Working Group (USGRWG)

Cost effectiveness of CubeSat platforms

- 18-24 months from concept formulation to deployment
- Approximately $1M including launch and basic operations

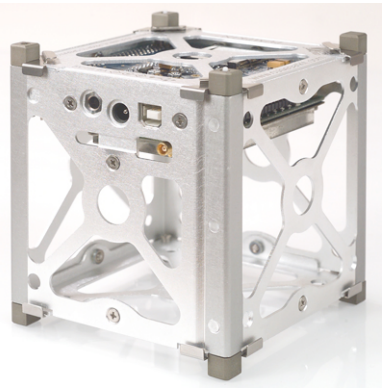
Rapid TRL advancement and risk reduction

- Meaningful risk reduction for hardware components and information systems developed for future flight instruments
- Demonstrated success stories across industry and educational institutions with substantial future growth

Emergence of industry standards

- 1U and 3U bus designs
- Orbital deployment mechanisms (P-POD) and others

ULA Delta II



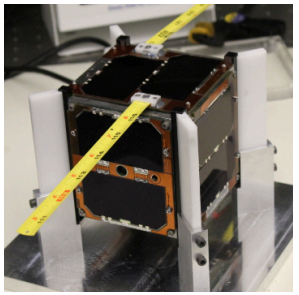
CubeSat Kit (Pumpkin Inc.)

1U: 10 cm x 10 cm x 10 cm

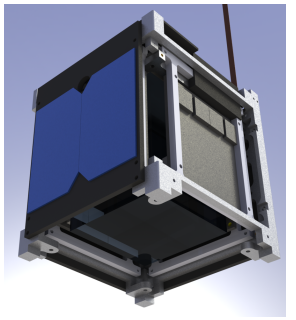
ESTO Technology Space Flight Validation

Partnering to flight qualify technologies through successful spaceborne demonstrations

- MCubed/COVE – Paula Pingree
  - CubeSat spaceborne validation of ACE/MSPI instrument signal processing algorithm on new Xilinx Rad-hard by design FPGA reducing data downlink by 2-orders of magnitude per camera
  - Partners: JPL, U. Michigan, Xilinx



- IPEX – Steve Chien
  - CubeSat spaceborne validation of Intelligent Payload Module (IPM) capability providing a 20-times reduction in data volume for low-latency urgent production generation planned for HyspIRI
  - Partners: JPL, GSFC, Cal Poly San Luis Obispo



- GRIFEX – David Rider
  - CubeSat spaceborne validation of state-of-the-art ROIC/FPA assessing functionality and data integrity for high frame rate imaging planned for GEO-CAPE
  - Partners: JPL, U. Michigan

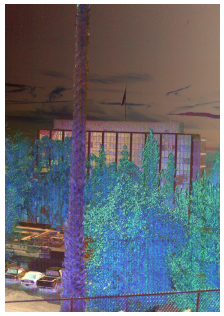
- First Launch with NPOESS Preparatory Project
  - MCubed/COVE: Secondary payload on NPP (VAFB on Oct 25, 2011)
  - IPEX: Awaiting ELaNa manifest (2012/2013)
  - GRIFEX: TBD (2013?)

ESTO CubeSat Flight Validation for Multiangle Spectropolarimetric Imager (MSPI) Processing for ACE

David Diner, Paula Pingree et al., JPL

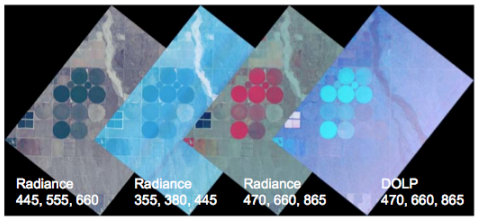
MSPI Ground-based measurements

470, 660, 865 nm Intensity

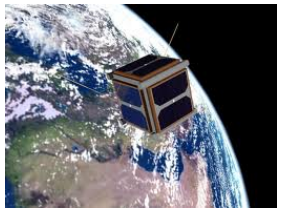


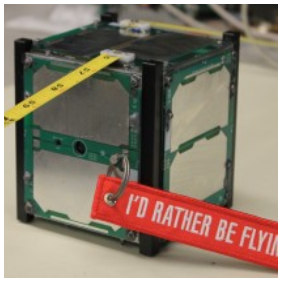
470, 660, 865 nm DOLP

MSPI Airborne engineering flight testing

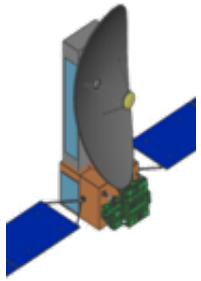


MSPI algorithms/FPGA on CubeSat operating in space environment

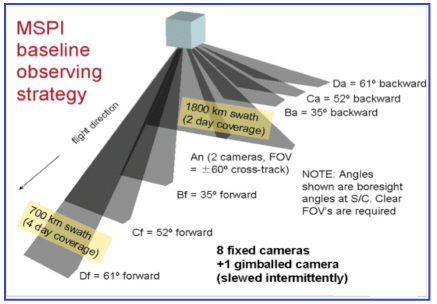




Multiangle polarimetric spectroscopy



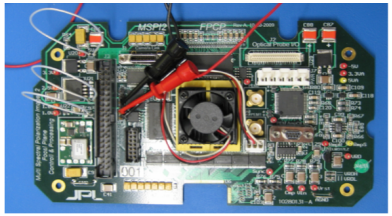
MSPI on ACE



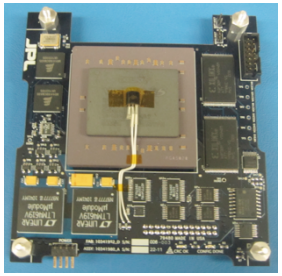
2011 Flight Validated MSPI instrument processor and algorithms

On-board instrument processing enables downlink by reducing data rate by 2-orders of magnitude in real time with no science data lost

IIP-07 and AIST-08 Ground Testbed Development and Demonstration



AIST-08 AirMSPI board with algorithms on Xilinx Virtex-5 FPGA



ATI-10 COVE CubeSat board with algorithms on Xilinx SIRF FPGA

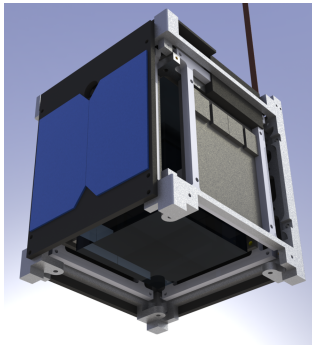
XILINX

UNIVERSITY OF MICHIGAN

IPEX: Intelligent Payload Flight Experiment
PI: Steve Chien, JPL

Objective

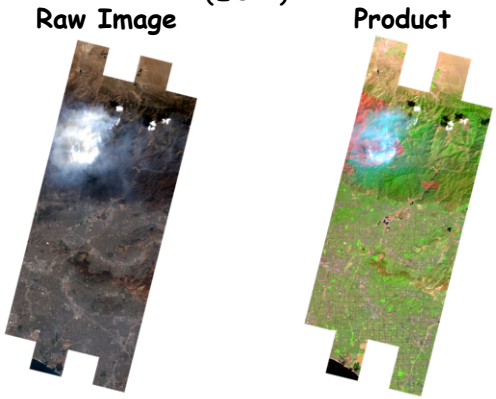
- Demonstrate hybrid onboard and ground capability (Intelligent Payload Module) for HyspIRI to deliver high value low-latency products via Direct Broadcast with at least 20x reduction in Gbps instrument raw data rate.
  - Spaceborne technology validation of the SpaceCube Mini hardware onboard computing platform.
  - Demonstrate web-based autonomous payload operations with event/overflight-based onboard product generation.
- Enhance NASA/University partnerships by engaging students and faculty in small satellite mission operations.



1U IPEX CubeSat carries:
- 2 Imaging cameras
- SpaceCube mini onboard processor
- IPM autonomy software

Candidate HyspIRI Low-latency Product

'09 Station Fire Burn Scar Severity Product (EO-1)



20x reduction via prioritization/compression

Approach

- Integrate SpaceCube Mini, high data rate camera, and autonomy algorithms into a 1U Cubesat as the onboard processing payload.
- Manifest CubeSat flight on a NASA, or other, launch vehicle.
- Downlink on-board derived and raw data for verification against ground tests.
- Validate onboard processing reliability and error rate on orbit.

Co-Is/Partners:

T. Flatley, GSFC, J. Puig-Suari, J. Bellardo, Cal Poly SLO

Key Milestones

• Hold preliminary design review; confirm CubeSat provider	06/11
• Hold critical design review	10/11
• Complete hardware subsystems; flight software operational on testbed	12/11
• Complete assembly and integration	03/12
• Complete integrated test; Flight readiness review	05/12
• First opportunity launch date (pending manifest)	06/12
• Nominal operations complete (pending launch)	12/12

$TRL_{in} = 4$ $TRL_{current} = 4$

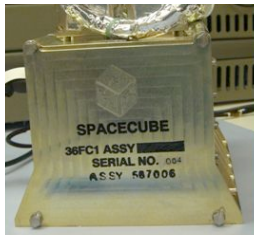
ESTO Earth Science Technology Office

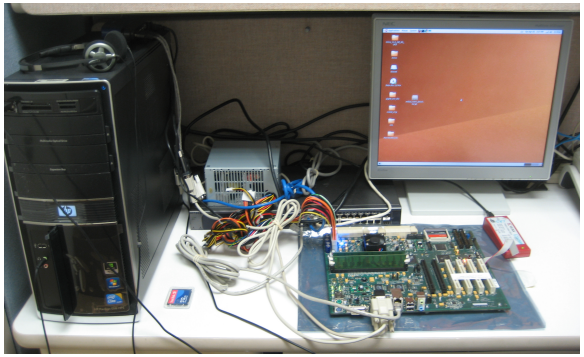
ESTO CubeSat Technology Validation of Intelligent Payload Modul for HyspIRI (IPEX)

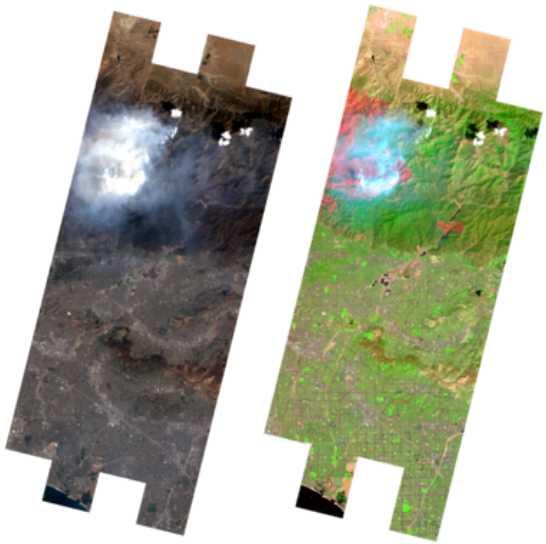
Intelligent Payload Module (IPM) for HyspIRI Decadal Survey Mission

- Provides low-latency Direct Broadcast mechanism for urgent products
- Visible to Shortwave Infrared Hyperspectral Spectrometer (VSWIR) and Thermal Infrared Imager (TIR) acquire 5 Tb/day of data
- IPM will provide 20x reduction in data volume for low-latency products

SpaceCube 1.5

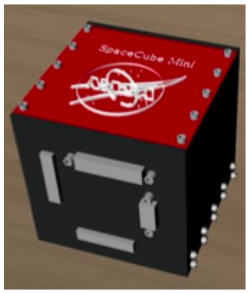




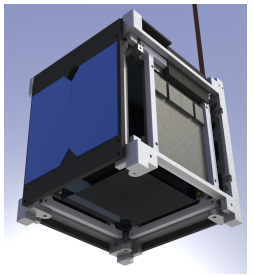


Burn Scar Severity Product (EO-1 ALI)
2009 Station Fire
Candidate HyspIRI Low-latency Product

SpaceCube Mini



Spacecube Mini used for instrument data processing for Direct Broadcast downlink



Ground Test

Development board with autonomous processing in laboratory environment

Spaceborne Validation

IPEX CubeSat will verify on-board product selection for the HyspIRI mission

IPEX System Design

Onboard Processing

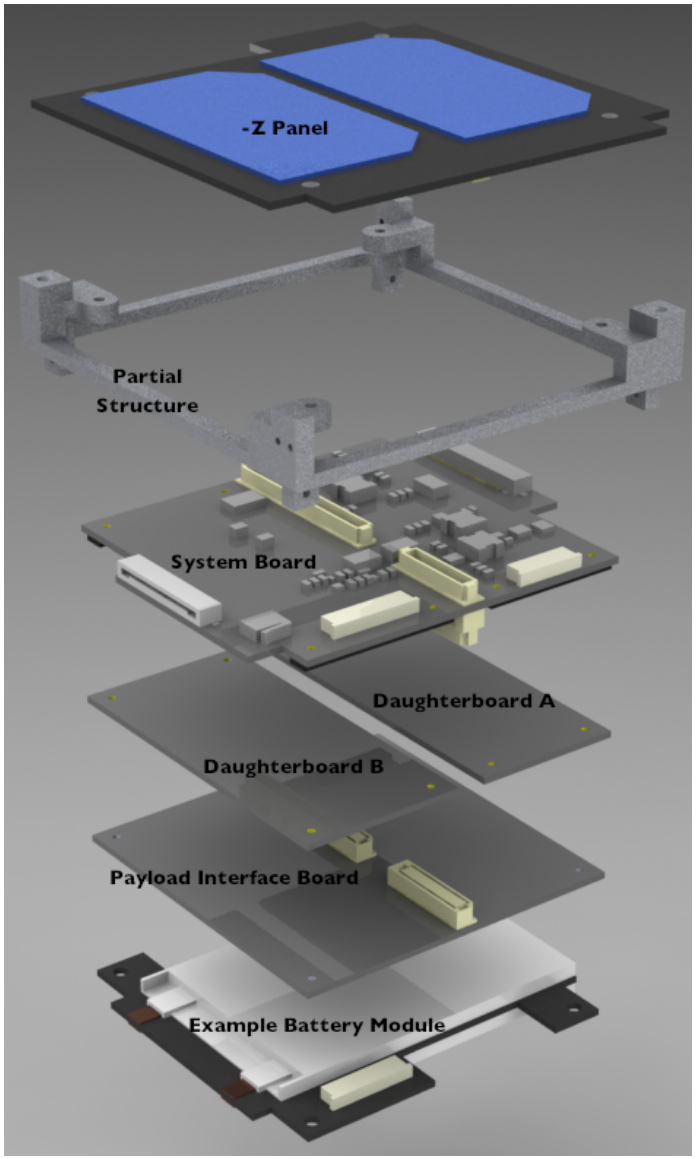
- Process images on ATMEL and SC Mini 2
- Compare products
- For some very small percentage, downlink products and raw data to verify (planned, or anomalies in compared results)
- For vast majority of products, downlink status of comparison (e.g. all checked out, same results)

OBP Candidate Algorithms

- Normalized Difference Vegetation Index
- Normalized Burn Ratio
- Brightness Temperature
- Support Vector Machine Classification Algorithms
- Others in evaluation

Autonomous Ground/Space Operations

- ASPEN (ground): Creates baseline schedule producing observations and processing activities
- CASPER (flight): Creates on-board science schedule based on previous observations



Engineering Model Design

Path-to-Flight Challenges

Spacecraft and Payload Design and Testing

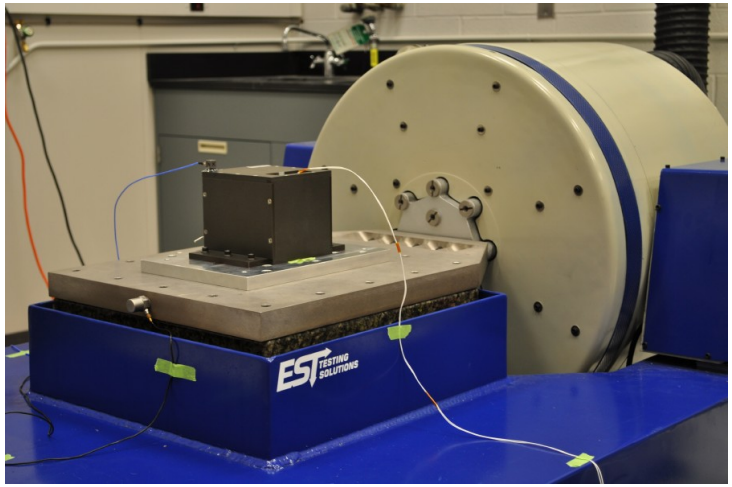
- Parts acquisition and fabrication
- Safety and Mission Assurance signed agreements
- ITAR / Export Control for specific parts and CubeSat spacecraft
- Testing and “safe-to-mate” procedures

Documentation

- Interface Control Documents (ICDs)
- FCC licensing
- End-of-Life (EOL) de-orbit plan
- NOAA licensing for Earth observing missions

NASA Launch Services Requirements

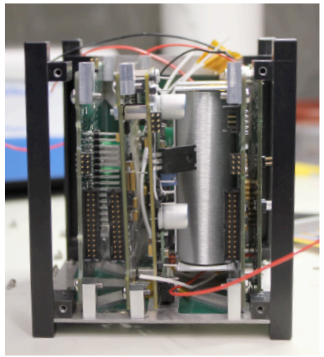
- CubeSat Interface Review (CIR)
- Launch Services Program Standard Material List
- Orbital Debris Assessment Report (ODAR)
- CubeSat Transmitter Characteristics Survey
- ELaNa Requirements Verification Documentation

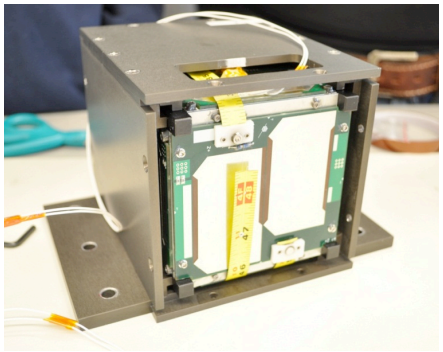


Mcubed/COVE mounted for vibration test

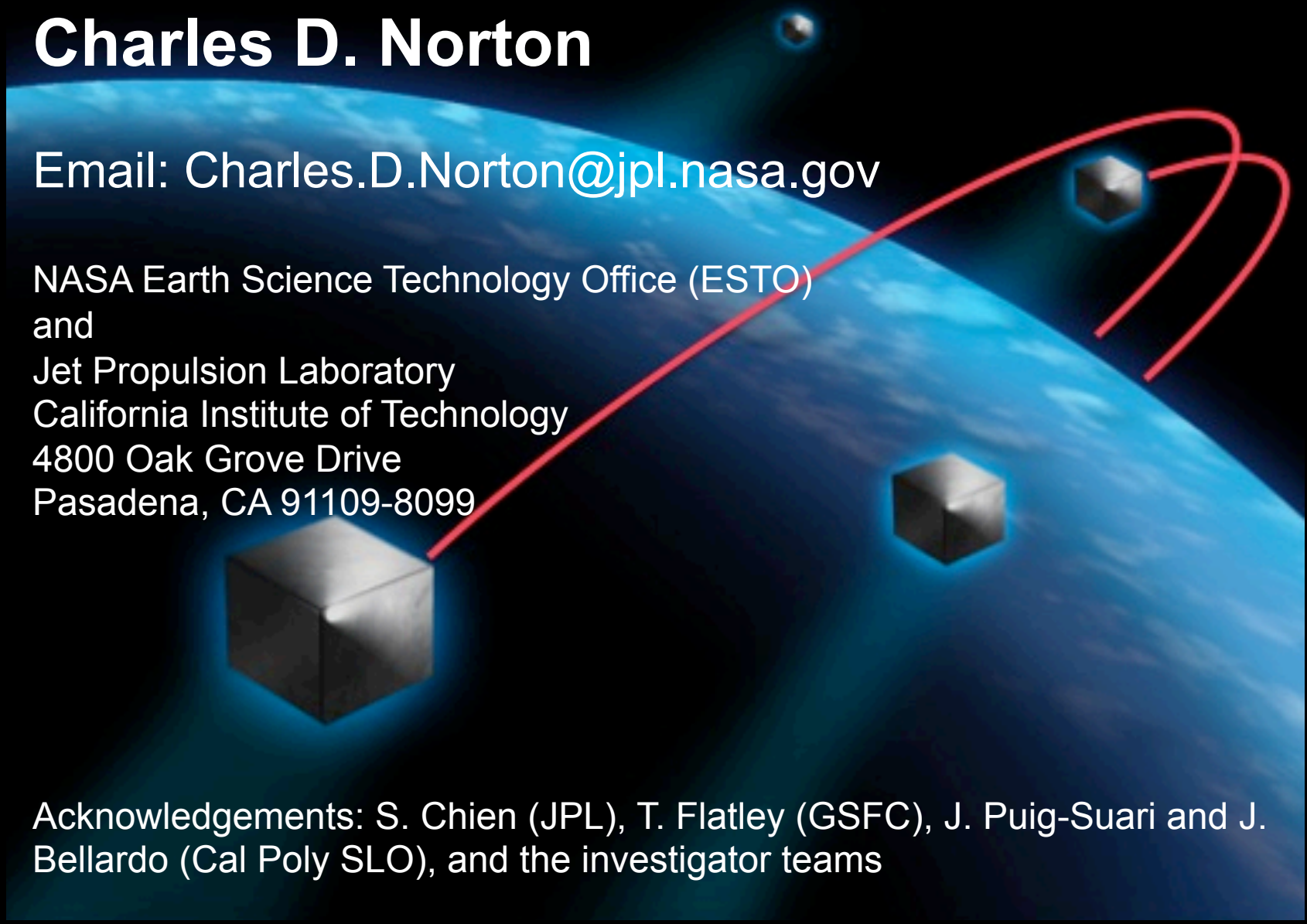
Qualification random vibe: (23.68 G’s for 104s)

Protoflight random vibe: (16.74 G’s for 180s)





Contact Information



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