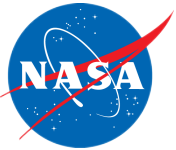# Technology Readiness Level (TRL) Advancement of the MSPI On-Board Processing Platform for the ACE Decadal Survey Mission

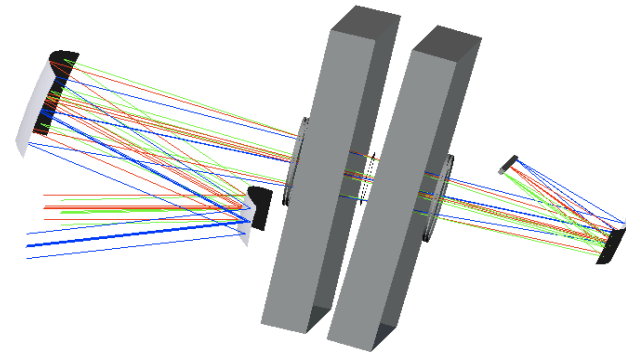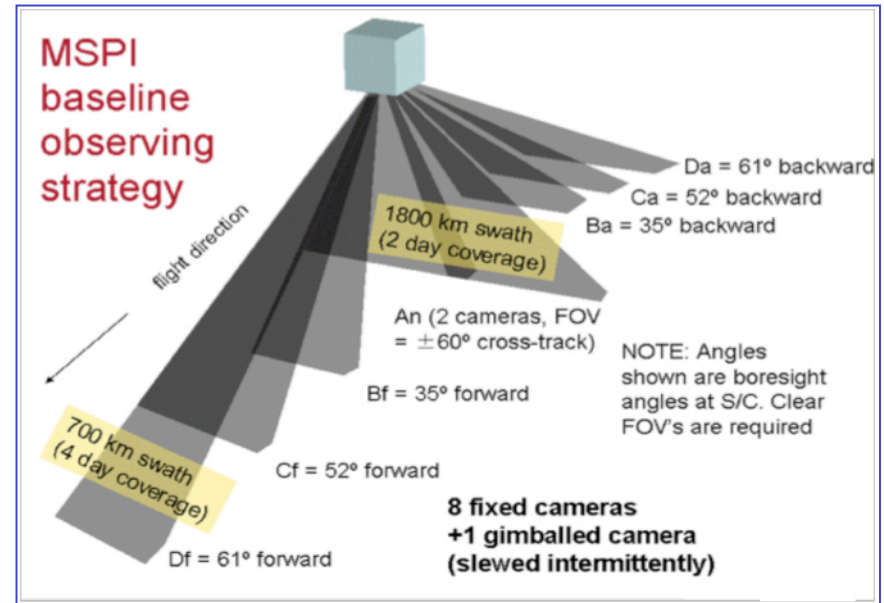**Paula J. Pingree**, Thomas A. Werne, Dmitriy L. Bekker, Thor O. Wilson

Jet Propulsion Laboratory
California Institute of Technology

June 21, 2011
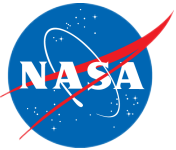
ESTO
Earth Science Technology Office

Multi-angle SpectroPolarimetric Imager (MSPI)

- Measures cloud and aerosol properties
- 8-fixed and 1-gimballed cameras, each with 16 channels
- Design goals
  - Acquire accurate multispectral intensity imagery
  - Acquire accurate degree of linear polarization (DOLP) imagery
- Two photo-elastic modulators (PEMs) in optical path for high accuracy in DOLP
- A single MSPI camera must process 95 Mbytes/sec of raw video data; data reduction to 0.45 Mbytes/sec is required

MSPI baseline observing strategy

flight direction

1800 km swath (2 day coverage)

700 km swath (4 day coverage)

Da = 61° backward
Ca = 52° backward
Ba = 35° backward

An (2 cameras, FOV = ±60° cross-track)

Bf = 35° forward

Cf = 52° forward

Df = 61° forward

NOTE: Angles shown are boresight angles at S/C. Clear FOV's are required

8 fixed cameras +1 gimballed camera (slewed intermittently)

The information technology processing challenge is to apply on-board processing to extract intensity and polarimetric parameters from the real-time data stream across each camera thereby reducing the data volume by 2-orders of magnitude without loss of science information.

- On-Board Processing (OBP) to Optimize the MSPI Imaging System for ACE
  - PI: Paula Pingree, Co-Is: Thomas Werne, Dmitriy Bekker
- Objectives:
  - Design an on-board instrument processing system to reduce the data rate by more than two orders of magnitude to meet the spectro-polarimetric image processing requirements for the MSPI instrument.
- ➤ We implement the MSPI OBP algorithm on the Xilinx Virtex-5FXT FPGA

 $TRL_{IN} = 4$, $TRL_{OUT} = 6$
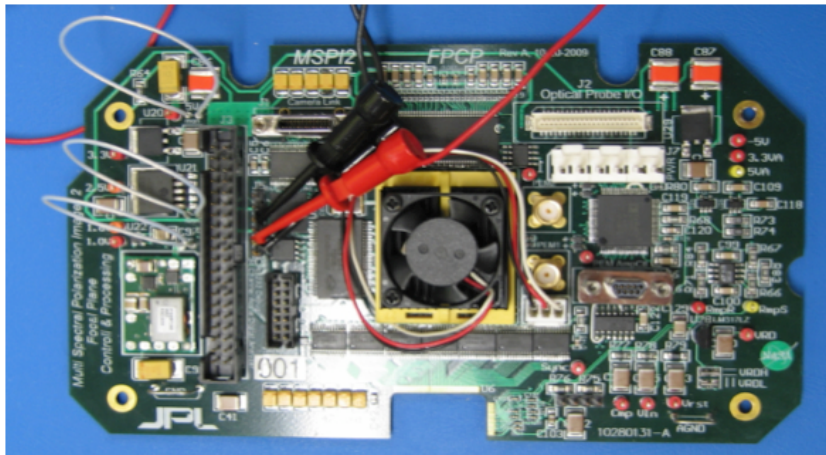
Air-MSPI Focal Plane Control Processor (FPCP) Board

Key Milestones

|	
Migrate/modify Virtex-4 linear least-squares processing to Virtex-5 system	09/09
Integrate FPGA development board system into MSPI camera brass-board in laboratory	06/10
Finish design trades on algorithm implementation to optimize performance	12/10
Finish design trades on other DSP train operations to simplify camera design	06/11
Test (airborne pending availability) integrated system on real-time data acquisition	02/12

Progressive Demonstration Plan

1.
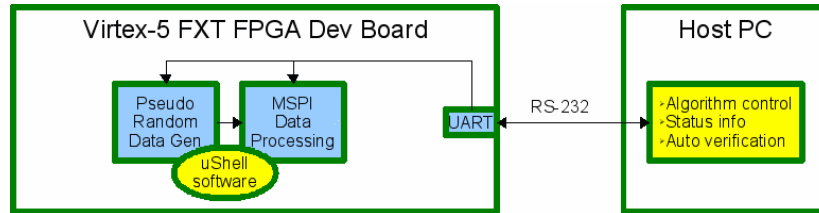
- Demonstrate MSPI data processing on pseudo-random data
- Auto verify results to known good values
- PC receives data / sends commands via UART
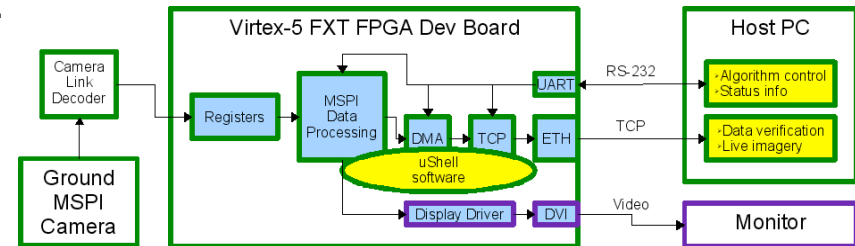- STATUS: Complete (8/09)

2.
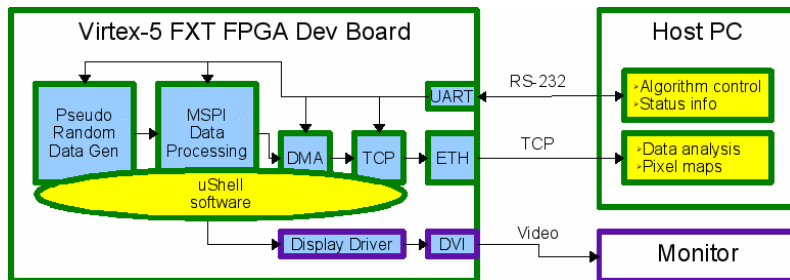
- Add DMA and TCP/IP functionality in order to send real-time processed MSPI data to host for analysis
- Optional: live video feed directly to monitor
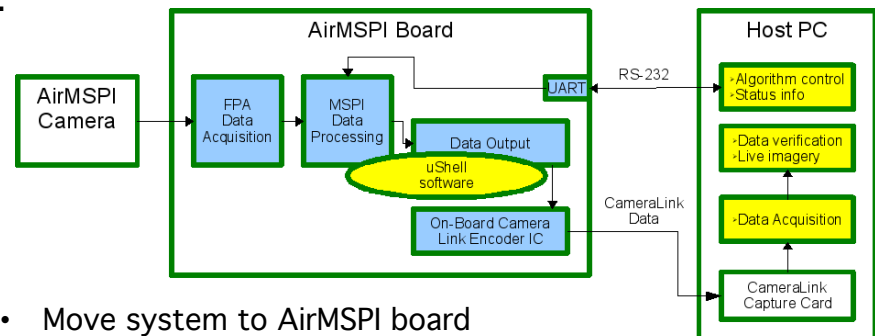- STATUS: Complete (1/10)

KEY
Blue: HW IP, Yellow: SW IP
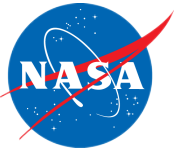Green outline: complete, Orange: work in progress, Purple: not started

3.

- Replace random generator with data formatter
- Grab raw data from Ground MSPI camera
- Send real-time processed MSPI data to host for analysis
- Optional: live video feed directly to monitor
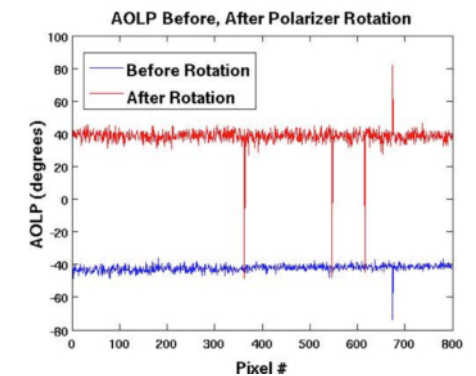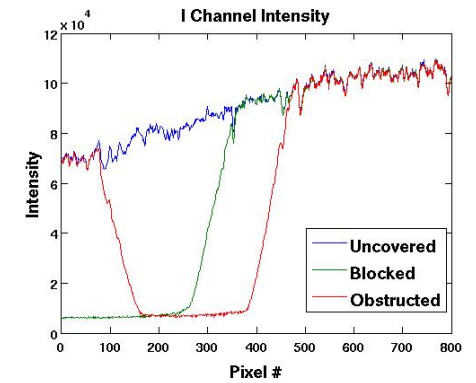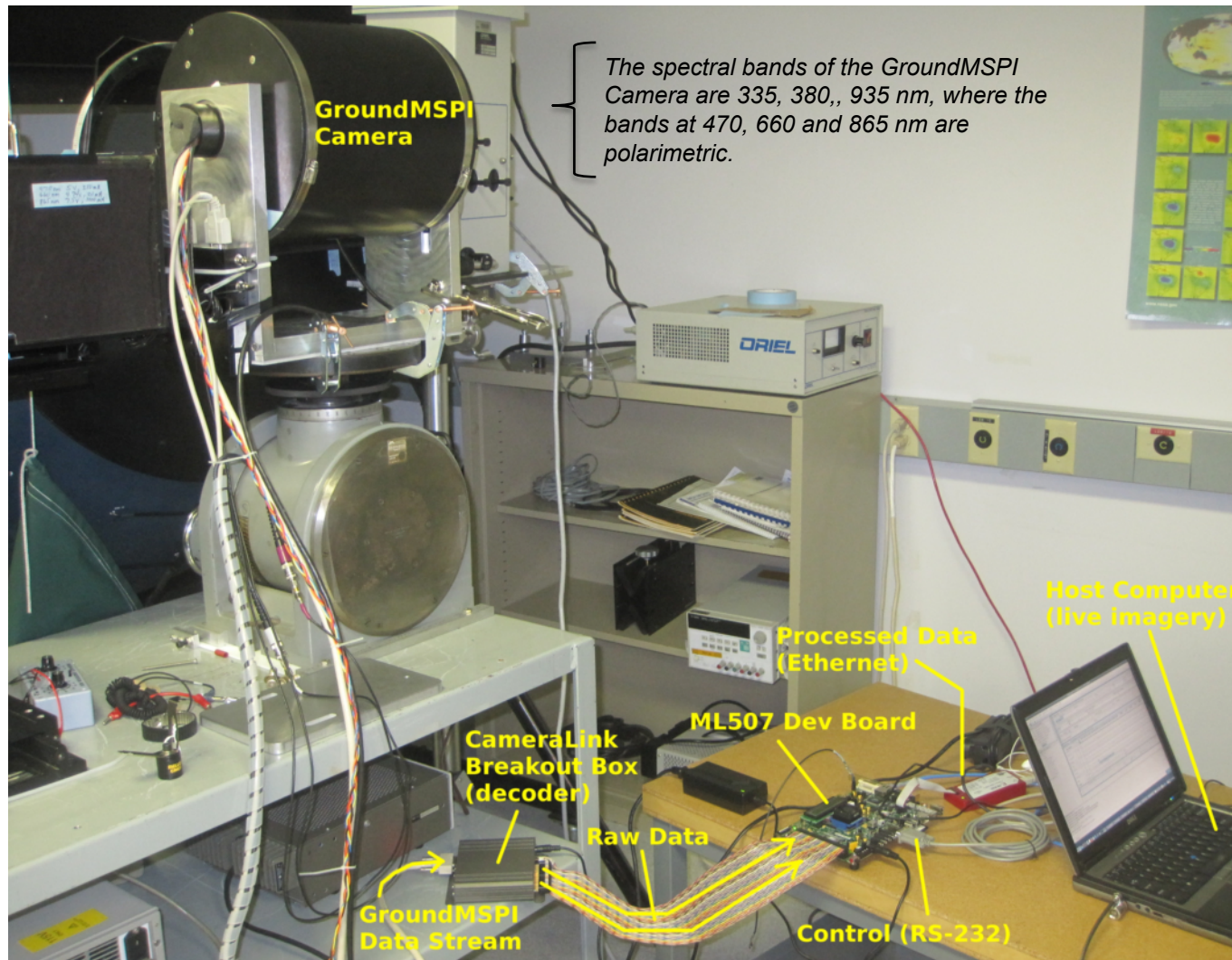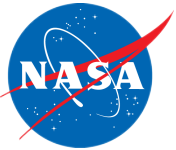- STATUS: Complete (5/10)

4.

- Move system to AirMSPI board
- Replace CameraLink front-end with FPA data acquisition
- Grab raw data from AirMSPI camera
- Send real-time processed MSPI data to host via on-board CameraLink encoder
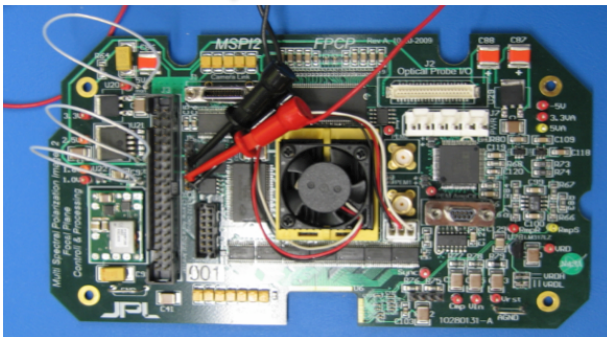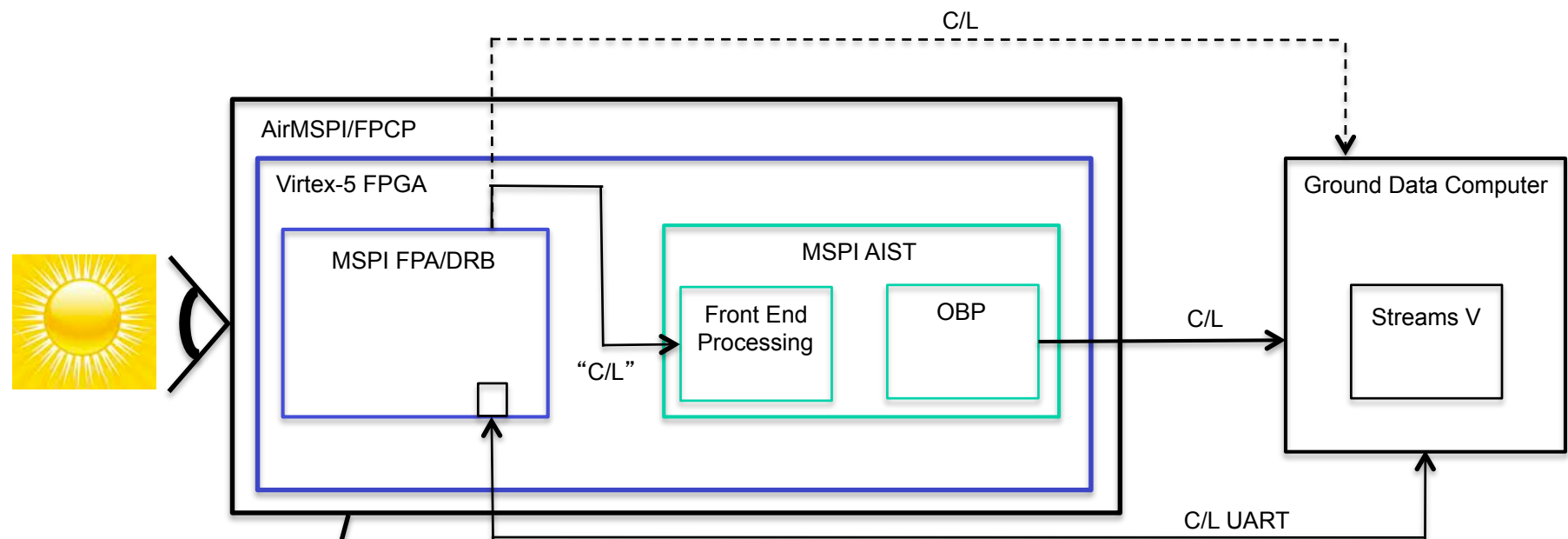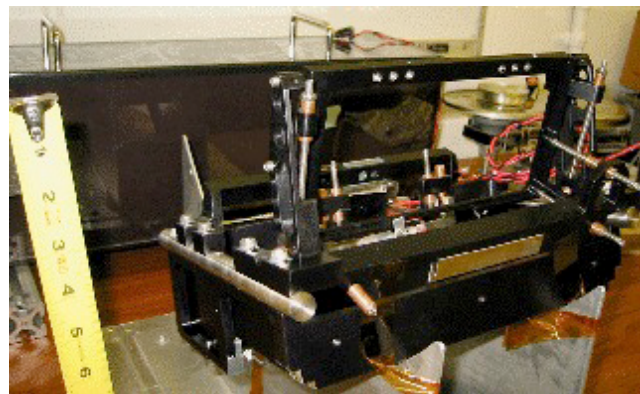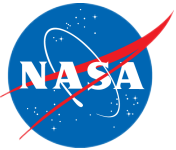- STATUS: Complete (1/11)

GroundMSPI Demo System

The spectral bands of the GroundMSPI Camera are 335, 380,, 935 nm, where the bands at 470, 660 and 865 nm are polarimetric.

GroundMSPI Camera

Host Computer (live imagery)

Processed Data (Ethernet)

ML507 Dev Board

CameraLink Breakout Box (decoder)

Raw Data

GroundMSPI Data Stream

Control (RS-232)

I Channel Intensity

- Uncovered
- Blocked
- Obstructed

Intensity

Pixel #

AOLP Before, After Polarizer Rotation

- Before Rotation
- After Rotation

AOLP (degrees)

Pixel #

ESTO
Earth Science Technology Office

Air-MSPI Demo System

AirMSPI/FPCP

Virtex-5 FPGA

MSPI FPA/DRB

"C/L"

MSPI AIST

Front End Processing

OBP

C/L

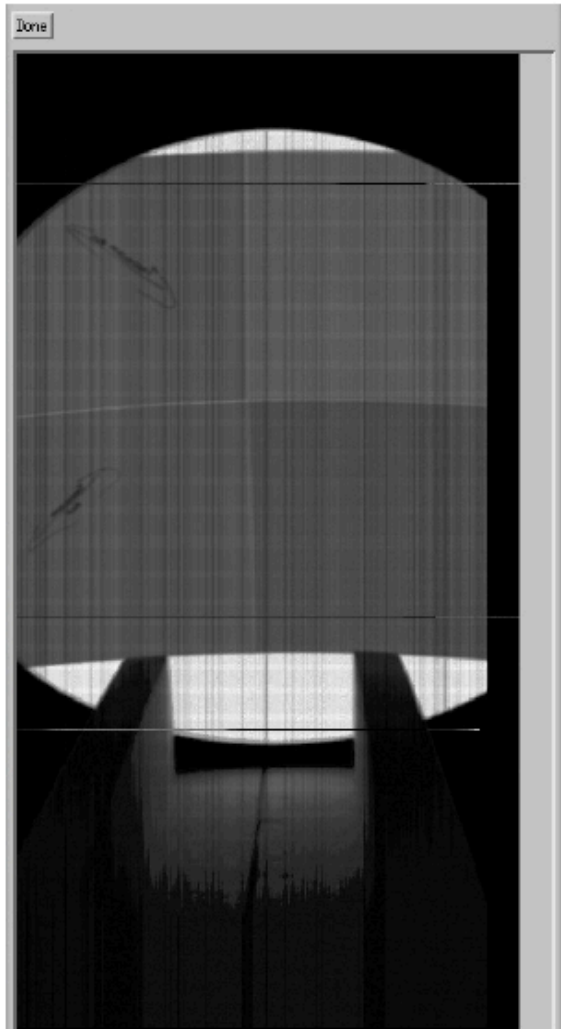Ground Data Computer

Streams V

C/L

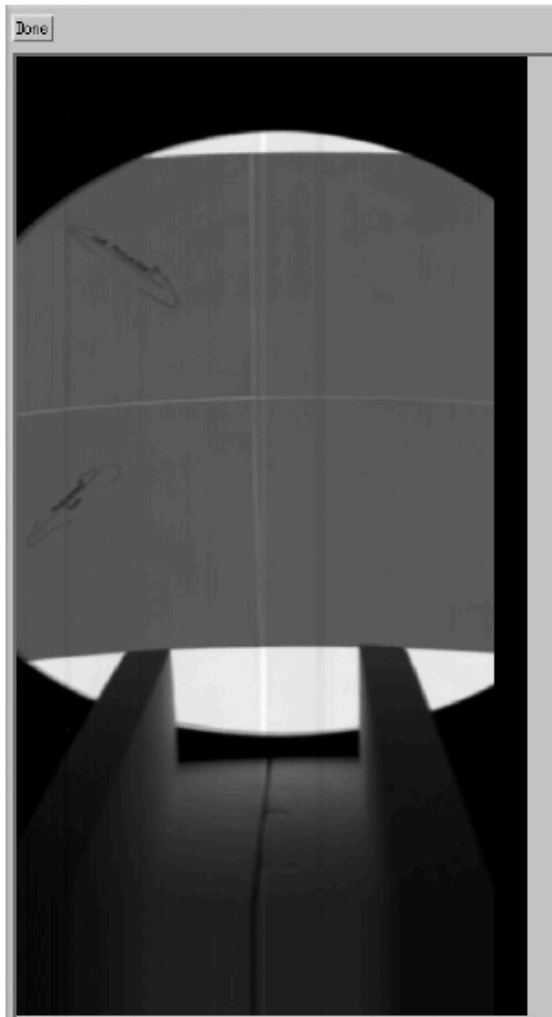C/L UART

Air-MSPI FPCP Board

Air-MSPI Camera in Lab

Air-MSPI Lab Demo Results

(a) OBP Processed

(b) Ground Processed

- Image Capture – collecting processed intensity produced by OBP algorithm

- Multiplexed Output – OBP algorithm output multiplexed into raw data stream and reconstructed on the ground

- Validation with Air-MSPI camera in Lab (in progress)

- Preparing for ER-2 Airborne Demonstration in July

ATI-10 Task: COVE
CubeSat On-board processing Validation Experiment

Spaceborne validation (of polarimetry algorithm and Virtex-5 FPGA) at low cost.
ACE MSPI polarimetry algorithm implemented on the Xilinx Rad-Hard-By-Design (RHBD) Virtex-5 FPGA and integrated into the U. Michigan M-Cubed CubeSat for space validation

PI: Paula Pingree (JPL)

Co-Is: Thor Wilson (JPL), Prof. Jamie Cutler (U. Michigan), Michael Heywood (U. Michigan)

Approach

• Complete development of the U. Michigan 1U CubeSat with a 2.0 Megapixel CMOS camera chip sensor and integration of the JPL image processing payload (featuring the Virtex-5QV SIRF)

• Manifest the flight on a NASA, or other, launch vehicle.

• Downlink on-board processing results and original image data for verification against ground tests.
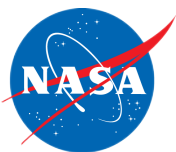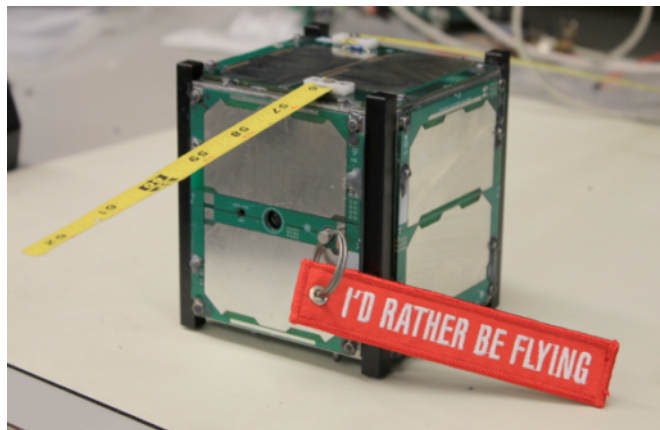
U. Michigan M-Cubed 1U CubeSat
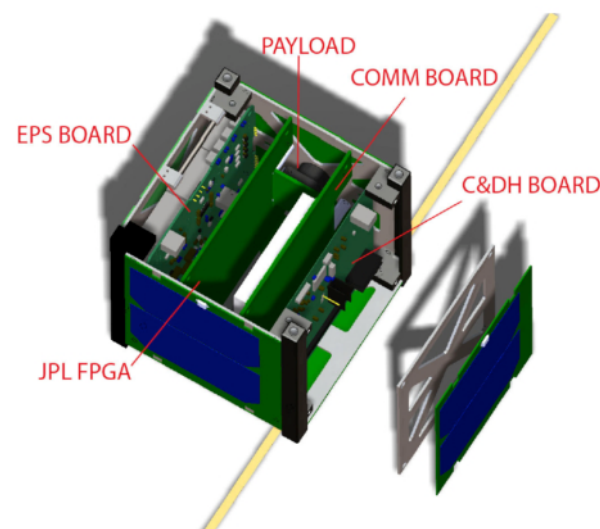
KEY MILESTONES

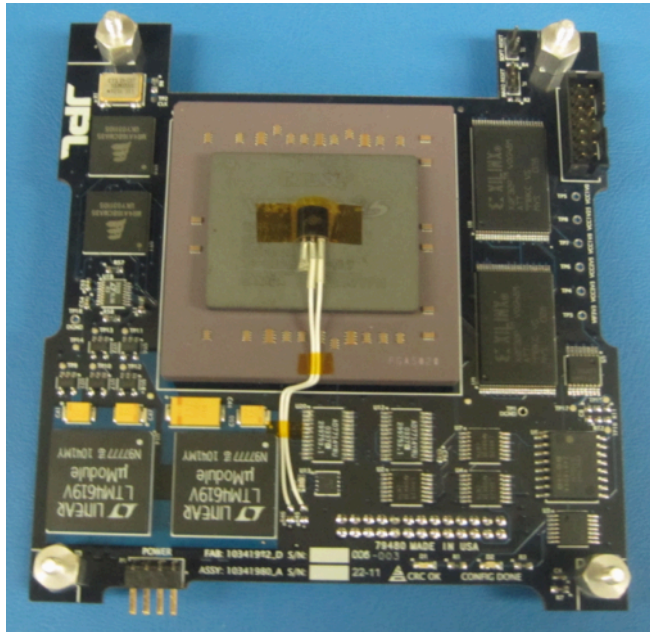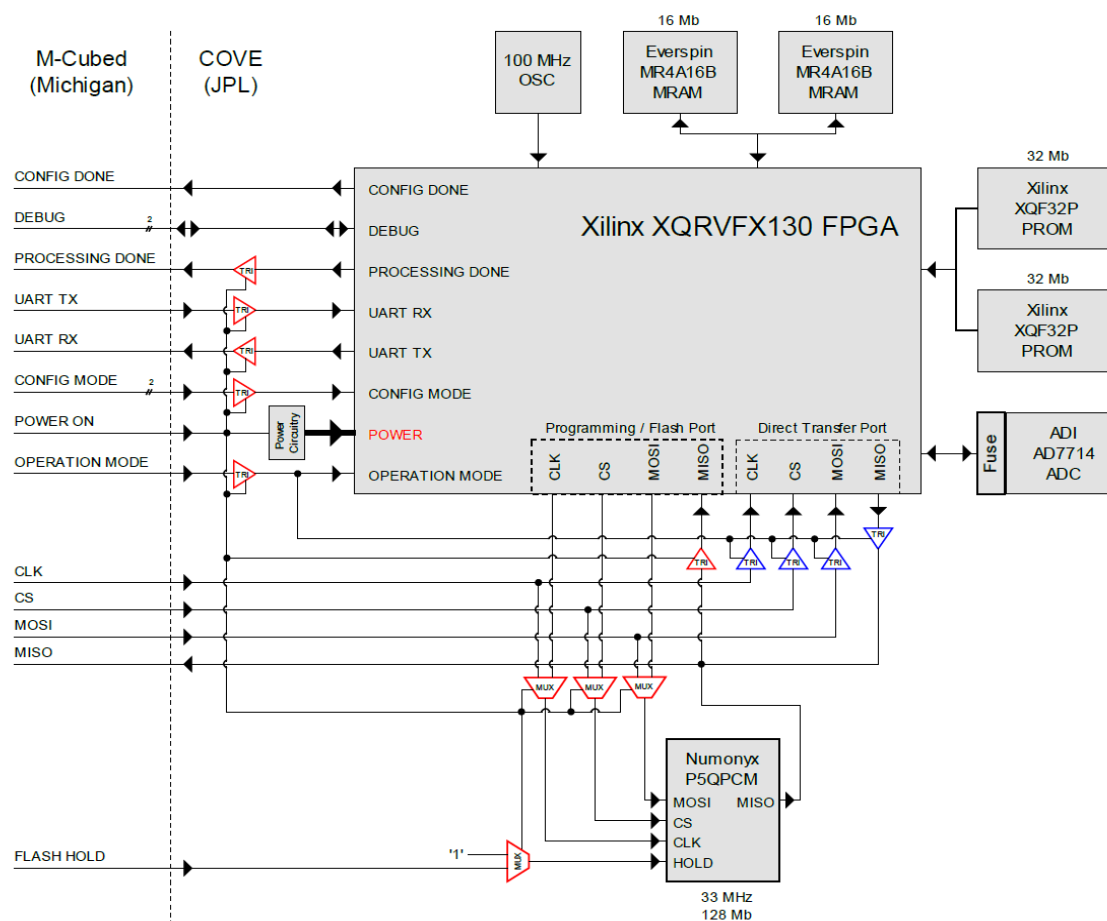|		
• Engineering development units for JPL payload board and U. Michigan CubeSat complete	12/10
• M-Cubed flight unit completed and JPL Flight FPGA payload board integrated	06/11
• Flight unit testing, launch and operations ready, final report	09/11

M-Cubed/COVE
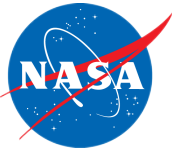
M-Cubed (Engineering Model)

COVE Payload Processor (ES Model)

COVE Payload: High-Level Design Diagram

NASA TRL4-8 Definitions

Technology Readiness Level (TRL)	Definition	Hardware Description	Software Description
4	COMPONENT or breadboard validation in laboratory	A low fidelity system/component breadboard is built and operated to demonstrate basic functionality and critical test environments and associated performance predicitions are defined relative to the final operating environment.	Key, functionally critical, software components are integrated, and functionally validated, to establish interoperability and begin architecture development. Relevant Environments defined and performance in this environment predicted.
5	COMPONENT or breadboard validation in a relevant environment	A mid-level fidelity system/component brassboard is built and operated to demonstrate overall performance in a simulated operational environment with realistic support elements that demonstrates overall performance in critical areas. Performance predictions are made for subsequent development phases.	End-to-end Software elements implemented and interfaced with existing systems/simulations conforming to target environment. End-to-end software system, tested in relevant environment, meeting predicted performance. Operational Environment Performance Predicted. Prototype implementations developed.
6	SYSTEM/ SUBSYSTEM model or prototype demonstration in a relevant environment	A high-fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	Prototype implementations of the software demonstrated on full-scale realistic problems. Partially integrate with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.
7	System prototype demonstration in space	A high fidelity engineering unit that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate performance in the actual operational environment and platform (ground, airborne or space).	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.
8	Actual system completed and flight qualified through test and demonstration	The final product in its final configuration is successfully demonstrated through test and analysis for its intended operational environment and platform (ground, airborne or space).	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. V&V completed..

AIST08:
 GroundMSPI (Lab)
 Air-MSPI (Lab)
 Air-MSPI (ER-2)

M-Cubed/COVE
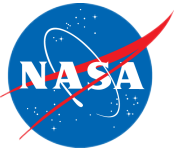
MSPI OBP TRL Assessment (Hardware)

Product breakdown			Technology Level Assessment	
System / Subsystem	Assembly	Component	Key Technology Items*	TRL
OBP for MSPI				**5**
OBP Hardware				
	Commercial Development Platform			4
		Xilinx ML510 Development Board	V5FX130T, Commercial grade FPGA	4
		Xilinx ML507 Development Board	V5FX130T, Commercial grade FPGA	4
	Ground-MSPI Camera			4
		Xilinx ML507 Development Board	V5FX130T, Commercial grade FPGA	4
	AirMSPI Camera			**5/6**
		AirMSPI Focal Plane Control Processor (FPCP) Board	V5FX70T, Military grade FPGA	**5/6**
	M-Cubed/COVE			
		COVE Payload Processor	V5FX130T, SIRF/ES (Rad-Hard) FPGA	8

Xilinx Virtex-5 FPGA
Commercial-grade BGA (w/PowerPC)

Xilinx Virtex-5 FPGA
SIRF/Engineering Sample (ES) CGA

MSPI OBP TRL Assessment (Firmware)

Product breakdown			Technology Level Assessment	
System / Subsystem	Assembly	Component	Key Technology Items*	TRL
OBP for MSPI				5
OBP Firmware				
	Commercial Development Platform			4
		IP: Multiply & Accumulate		4
		IP: Local Link DMA Front-End		4
	Ground-MSPI Camera			4
		IP: Multiply & Accumulate		4
		IP: Local Link DMA Front-End		4
	AirMSPI Camera			5/6
		IP: Multiply & Accumulate		5/6
	M-Cubed/COVE			
		IP: Multiply & Accumulate		7
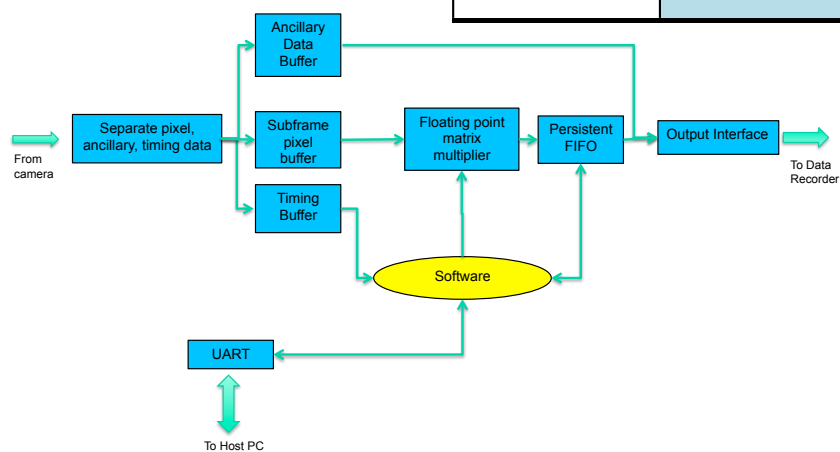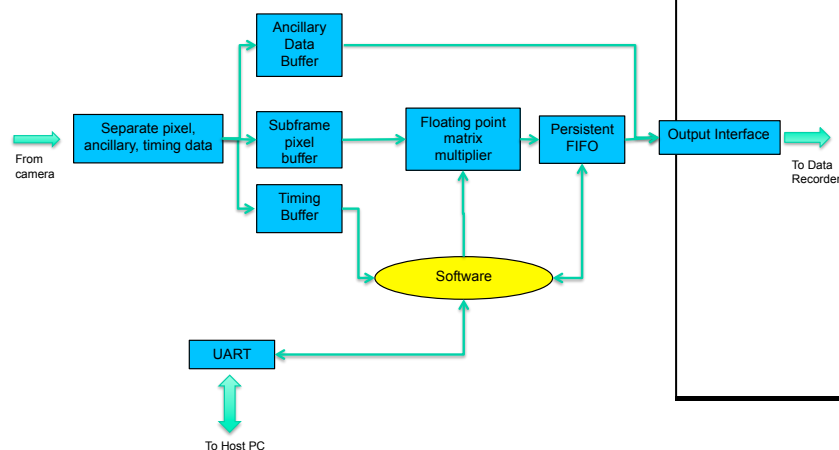
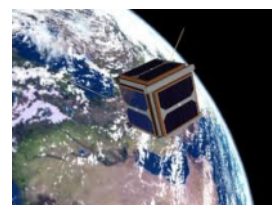| Product breakdown			Technology Level Assessment	
System / Subsystem	Assembly	Component	Key Technology Items*	TRL
OBP for MSPI				**5**
OBP Software				
	Commercial Development Platform			**4**
		uShell		5
		MSPI Algorithm Parameter Generation Code		4
		System Initialization Software		4
	Ground-MSPI Camera			**4**
		uShell		5
		MSPI Algorithm Parameter Generation Code		4
		System Initialization Software		4
	AirMSPI Camera			**5/6**
		uShell		**5/6**
		MSPI Algorithm Parameter Generation Code		**5/6**
		System Initialization Software		**5/6**
	M-Cubed/COVE			
		MSPI Algorithm Parameter Generation Code		7
		System Initialization Software		7
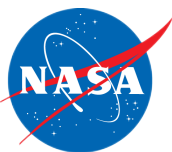
13

MSPI Ground-based measurements

MSPI Airborne engineering flight testing
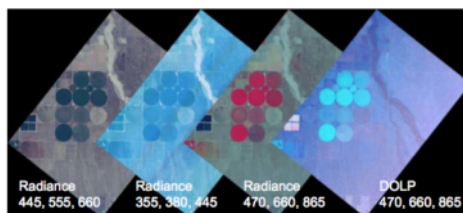
MSPI algorithms/FPGA on CubeSat operating in space environment

Multiangle polarimetric spectroscopy

470, 660, 865 nm Intensity

470, 660, 865 nm DOLP

Radiance 445, 555, 660 | Radiance 355, 380, 445 | Radiance 470, 660, 865 | DOLP 470, 660, 865

MSPI on ACE

TRL-4   **TRL-5**   **TRL-6**   **TRL-7 ...**

MSPI baseline observing strategy
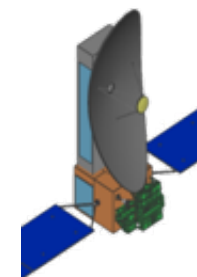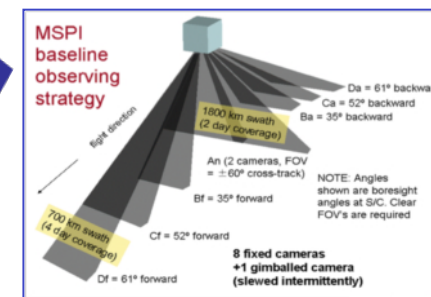
2011 *Flight Validated* MSPI instrument processor and algorithms

IIP-07 and AIST-08 Ground Testbed Development and Demonstration
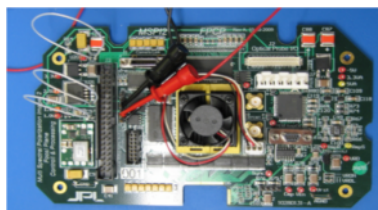
AIST-08 AirMSPI board with algorithms on Xilinx Virtex-5 FPGA

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

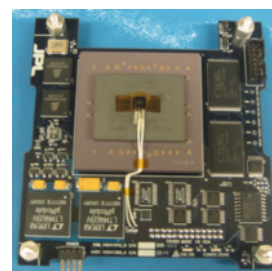On-board instrument processing enables downlink by reducing data rate by 2-orders of magnitude in real time with no science data lost

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Chart courtesy of Charles D. Norton