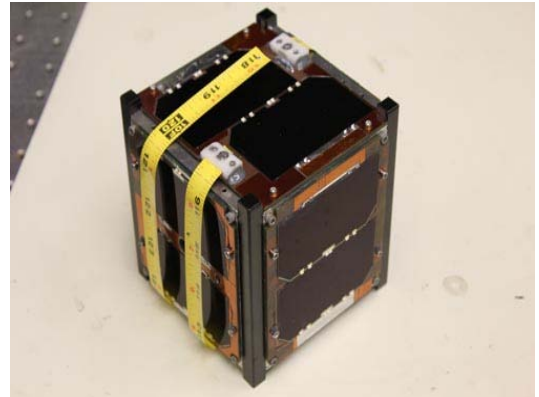
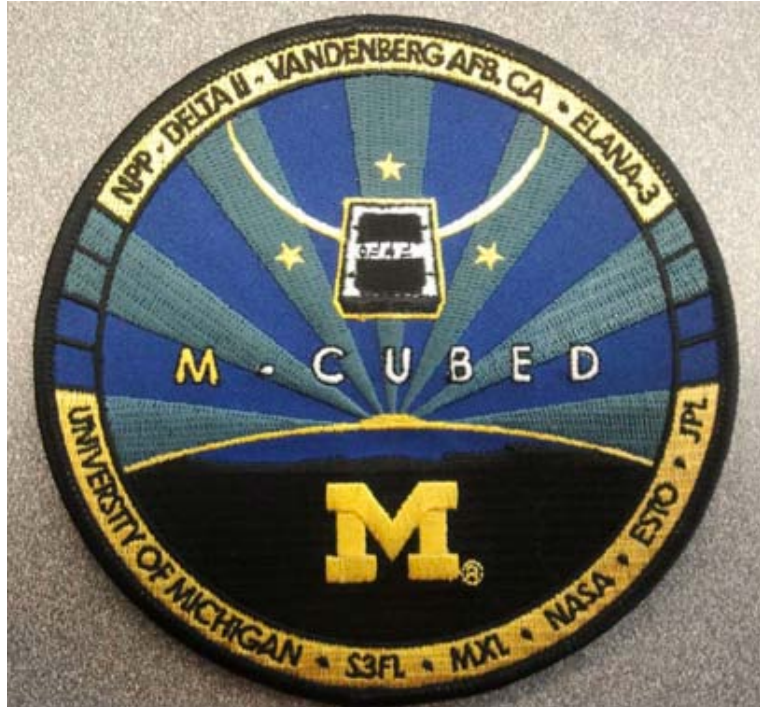




The M-Cubed/COVE Mission



Matt Bennett¹, Andrew Bertino², James Cutler²,
Charles Norton¹, Paula Pingree¹, John Springmann², Scott Tripp²
CubeSat Developers' Workshop
April 18, 2012



¹ Jet Propulsion Laboratory
² University of Michigan





What is M-Cubed / COVE?



- M-Cubed was an all-student CubeSat effort started in 2007 at UMich
- Original Mission Objective: Capture and downlink an image of Earth using a 1.3 MP CMOS camera
- Mission objective expanded in Summer 2010 to flight test a processing algorithm and Virtex-5QV FPGA as part of JPL's CubeSat Onboard processing Validation Experiment (COVE)
- Given 16 months from time of new sponsorship to deliver completed CubeSat for launch
- Over 50 students participated



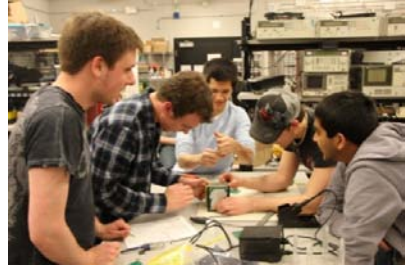
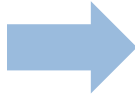
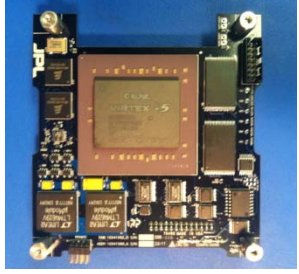
The Challenge: The Multi-angle Spectropolarimetric Imager (MSPI - Instrument Incubator Program, Diner/JPL), a candidate for the ACE mission, will produce 95 Megabytes per second per camera and there are *nine* cameras. There is currently no way to get that amount of raw data from space to the ground.

A Solution: Move the first stage of ground processing on-board the satellite in a new radiation-hard-by-design FPGA. This would reduce downlink requirements by *two orders of magnitude*.

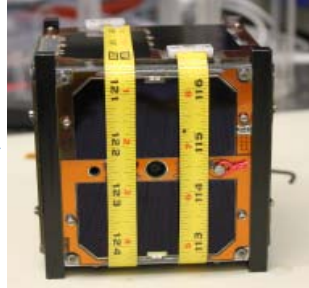
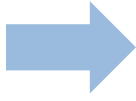
Implementation: The MSPI algorithm and new FPGA would be validated in flight on a CubeSat built by the University of Michigan's Student Space Systems Fabrication Laboratory (S3FL). Access to space enabled via NASA SOMD's CubeSat Launch Initiative (ELaNa).

Real-time Onboard Processing for MSPI (AIST, Pingree/JPL)

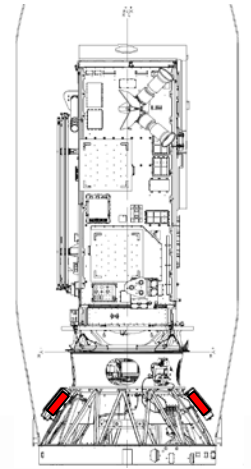
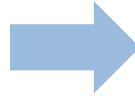
Xilinx Virtex-5QV FPGA



Michigan COVE S3FL Team



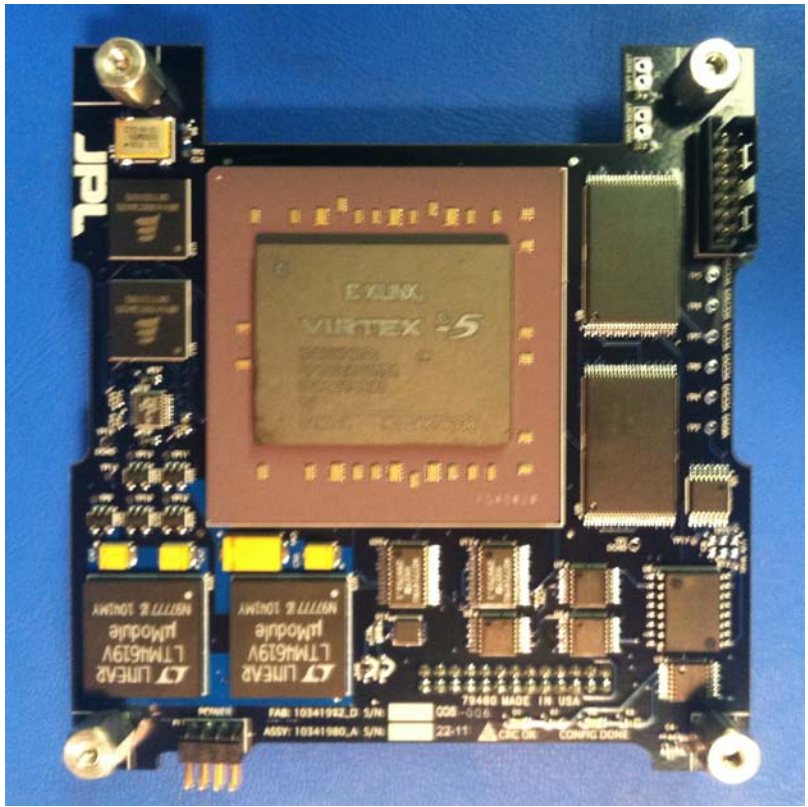
COVE Flight Unit



NPP Satellite and P-PODS (in red) on the Struts

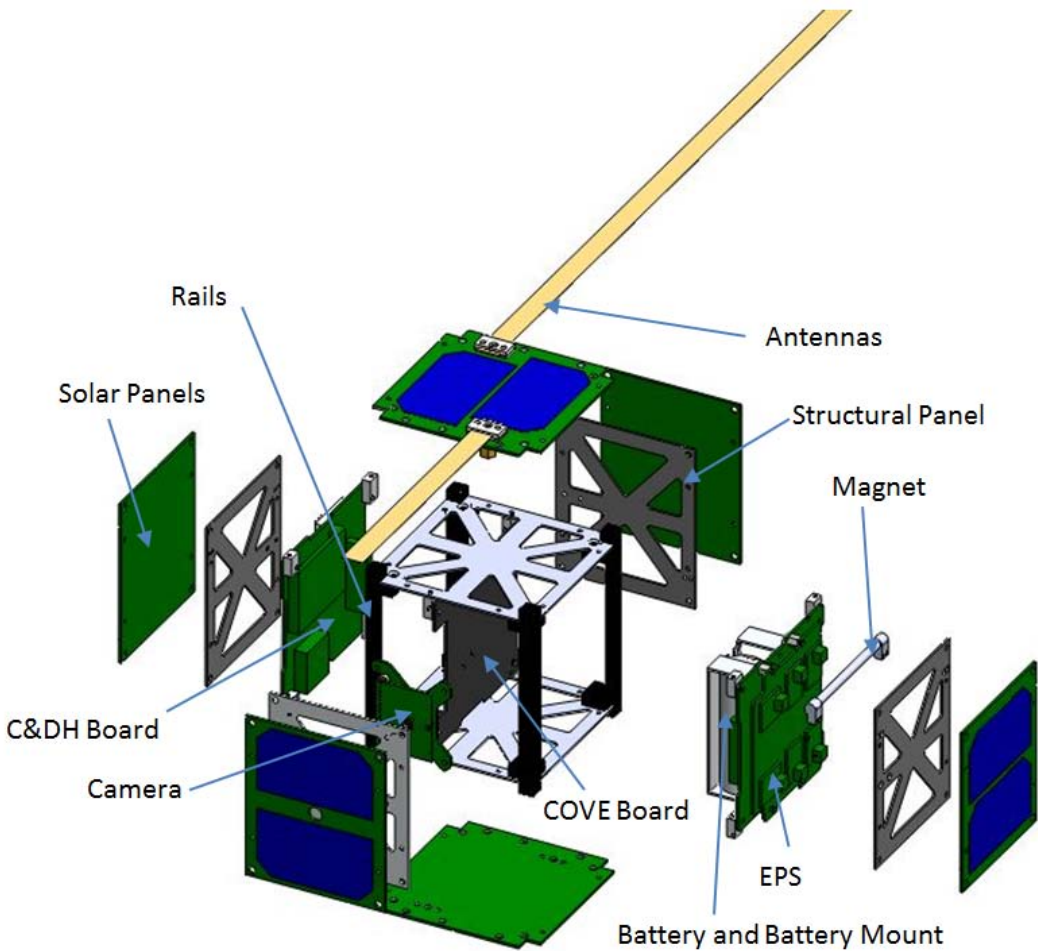
Overview

- Fully populated board before and after conformal coating
- JPLs 1st flight installation of 1752-pin CCGA device



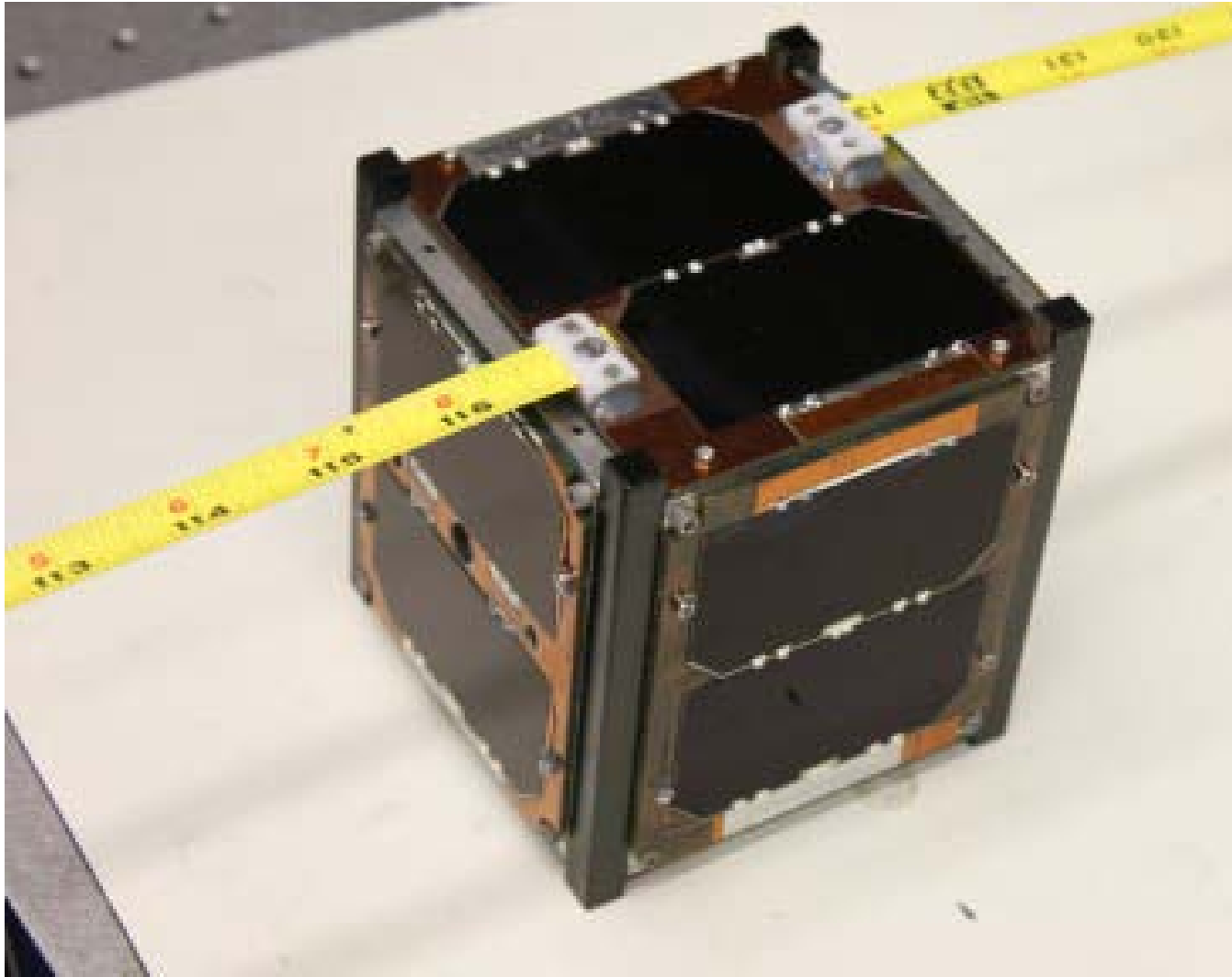


M-Cubed Flight Model (FM) Design





Flight Unit Before Delivery

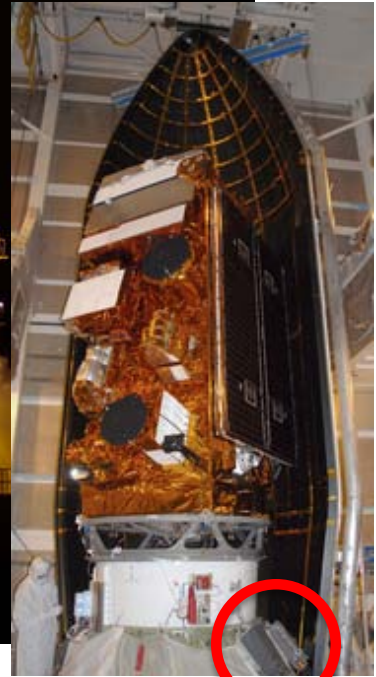




Launch – October 28, 2011



ELaNa III – NPP Launch





NPP Mission Flight Profile



P-POD-1

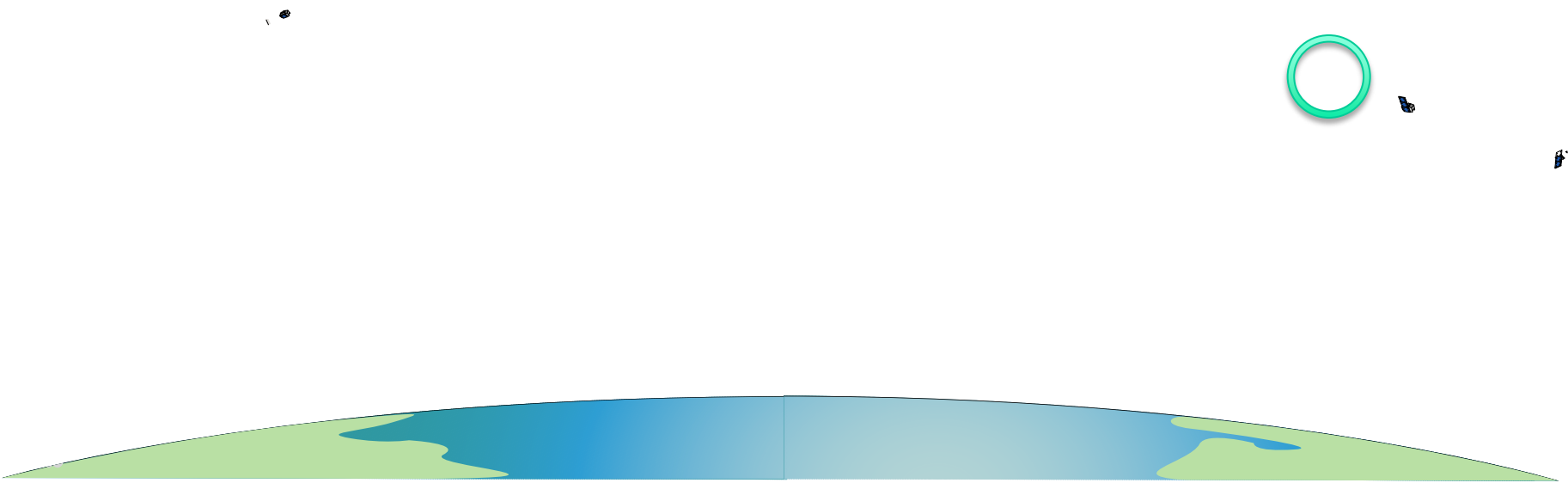
- AubieSat-1 (Auburn)
- Explorer-1 [Prime, Unit 2] (Montana State)
- M-Cubed/COVE (Michigan/JPL)

P-POD-2

- RAX (Michigan/SRI)

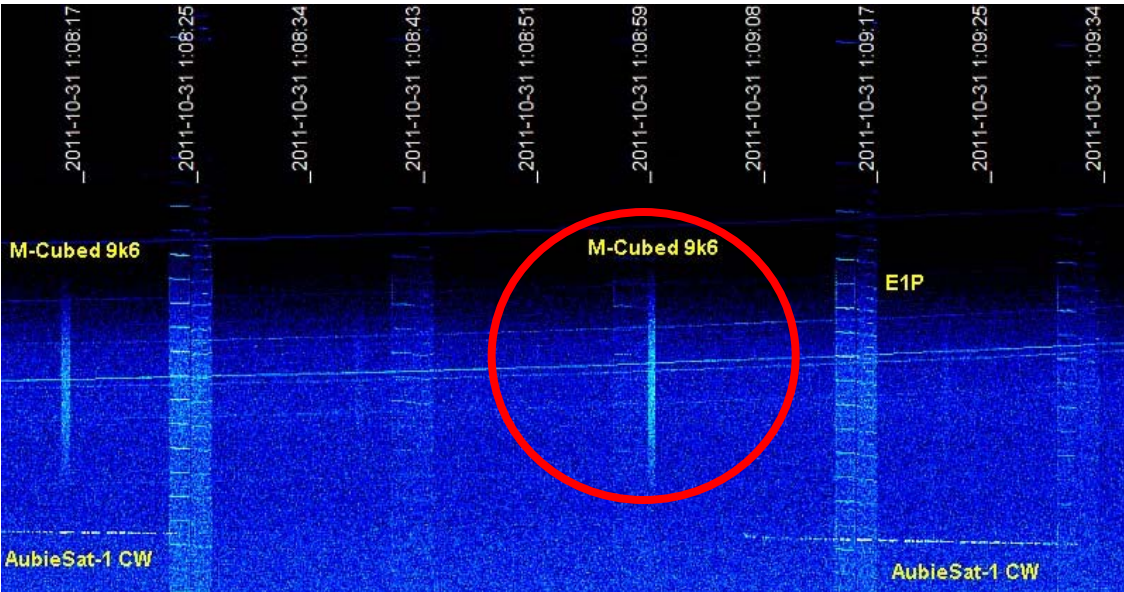
P-POD-3

- DICE (Utah State)





First Acquisition



First signals received on 10/31 and decoded beacons on 11/5 confirmed that M-Cubed was **alive and power positive**.

Why is the signal so weak?

The screenshot shows the 'MCubed Ground Station Client' interface. It contains several data tables:

COVE			Camera			EPS Output Board		
Name	Value	Unit	Name	Value	Unit	Name	Value	Unit
COVE_CONFIG0	0		Camera 3.3V Current	0	mA	3.3V Regulator Temp	13.8031	deg C
COVE_UART_TX	0		Camera 2.5V Voltage	2.024	V	5V Regulator Temp	13.2347	deg C
COVE_UART_RX	0		CAM_I2C_SDA	1		Raw Battery Current	80.3025	mA
COVE_PROCESS_DONE	0		CAM_I2C_SCL	1		Battery Warning	2403	
COVE_CONFIG1	1		CAM_O_D2	1		Antenna Release Curr...	0	mA
COVE Flash	0		CAM_O_D3	0		Cell Voltage	3.999	V
COVE_INPROC	0		CAM_O_D4	0		1.5V Current	0.58	mA
COVE_SUPP_BV_in	0		CAM_O_D5	0		3V Current	19	mA
COVE	0		CAM_O_D6	0		3.3V Voltage	3.321	V
COVE_DONE	0		CAM_O_D7	0		VBatt Current	15	mA
			CAM_O_D8	0		5V Voltage	4.998	V
			CAM_O_D9	0		VBatt Voltage	8.051	V
			CAM_O_PCLK	0				
			CAM_O_SPIK	0				
			CAM_O_HTRF	0				
			CAM_I_XCLK	0				
			PWRDN_CAM	1				
			Camera Status	1				

EPS Solar Input Board			FCPU			Radios		
Name	Value	Unit	Name	Value	Unit	Name	Value	Unit
V_SA1 (4V)	1.16	V	CDH 3.3V Current	139.2	mA	Lithium VBatt Current	0	mA
V_SA2 (2)	1.225	V	FCPU 3.3V Voltage	3.31	V	Lithium 3.3V Current	42.7	mA
V_SA3 (1V)	1.215	V	FCPU 5V Voltage	4.996	V	Lithium NCM	7058	commands
V_SA4 (4V)	0	A	FCPU Temperature	14	deg C	Lithium Radio Temp	-210	deg C
V_SA5 (2)	0	A	RTC Unix Time	72908		Lithium I2	64	deg C
V_SA6 (2)	0	A	NumReacts	27		Lithium RSSI	27.5	dBm
V_SA123A	0.8696	deg C	avgNumActiveTasks1	0		Queue Status	0	packets
V_SA4 (4x)	0.482	V	avgNumActiveTasks5	0		Lithium 9RX	0	bytes
V_SA5 (3x)	0.515	V	avgNumActiveTasks15	0		Lithium #TX	649284	bytes
V_SA6 (42)	1.21	V	curNumRunnableTasks	0				
V_SA7 (4x)	0	A	totNumProcesses	42				
V_SA8 (2)	0.0005	A	totProcessPID	3536				
T_SA456A	9.8696	deg C	totMemB	1332				
EPS Register MPPPT Sta...	0		freeMemB	2452				
ADC Reference	0	reference	L11	0				
OND	0	V	L10_RX	1				
T_SA123B	10.3015	deg C	L10_TX	1				
T_SA123B	9.8696	deg C	CDH GPIO MPPPT Status	0				
Reset Condition	5		L10	0				
			EPS_ANTENNA_DEPLOY	0				

EPS Solar Input Board		
Name	Value	Unit
V_SA1 (4V)	1.16	V
V_SA2 (2)	1.225	V
V_SA3 (1V)	1.215	V
V_SA4 (4V)	0	A
V_SA5 (2)	0	A
V_SA123A	0.8696	deg C
V_SA4 (4x)	0.482	V
V_SA5 (3x)	0.515	V
V_SA6 (42)	1.21	V
V_SA7 (4x)	0	A
V_SA8 (2)	0.0005	A
T_SA456A	9.8696	deg C
EPS Register MPPPT Sta...	0	
ADC Reference	0	reference
OND	0	V
T_SA123B	10.3015	deg C
T_SA123B	9.8696	deg C
Reset Condition	5	

5 Nov 2011 07:13:07 GMT
 5 Nov 2011 07:13:07 GMT
 5 Nov 2011 07:13:07 GMT
 5 Nov 2011 07:13:07 GMT
 5 Nov 2011 07:13:07 GMT
 5 Nov 2011 07:13:07 GMT
 5 Nov 2011 07:13:07 GMT
 5 Nov 2011 07:13:07 GMT
 5 Nov 2011 07:13:07 GMT



Images courtesy of Mike Rupprecht (DK3WN)





Post-Deployment CubeSat "Lottery"



**WHERE IS
M-CUBED??**

SatID	Object	Launch Date	RCS	ID'd As	ID Date
37850	OBJECT B	2011-10-28	1.698	NOT NPP Launch Object	
37851	OBJECT C	2011-10-28	0.136	DICE 1	11.02.2011
37852	OBJECT D	2011-10-28	0.183	DICE 2	11.02.2011
37853	OBJECT E	2011-10-28	0.103	RAX-2	11.02.2011
37854	OBJECT F	2011-10-28	0.047	AubieSat-1	11.25.2011
37855	OBJECT G	2011-10-28	0.055	E1P	12.01.2011

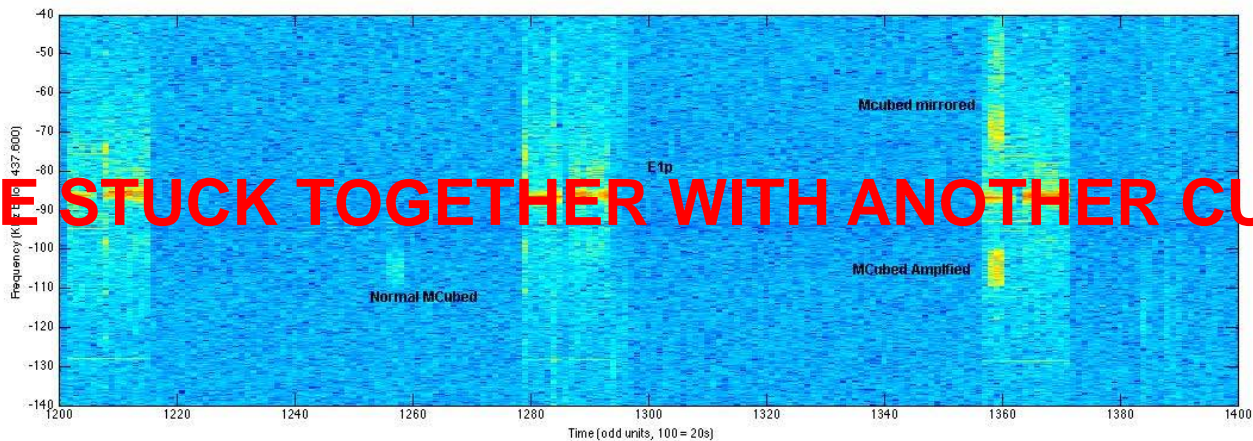




Unusual Behaviors and Interesting Info



- 1) M-Cubed had some unusual and concerning telemetry...
 - Two solar panels developing potential, but generating little to no current
 - Received Signal Strength Indicator (RSSI) off the scale (> -30 dBm)
 - Reset count showed spacecraft was resetting frequently
- 2) Every fourth beacon came in MUCH stronger than the preceding three, and was overlapping with E1P beacon transmissions
- 3) Joint Space Operations Center did NOT observe any other objects related to the NPP launch since first acquisition of the other 5 spacecraft



ARE WE STUCK TOGETHER WITH ANOTHER CUBESAT?

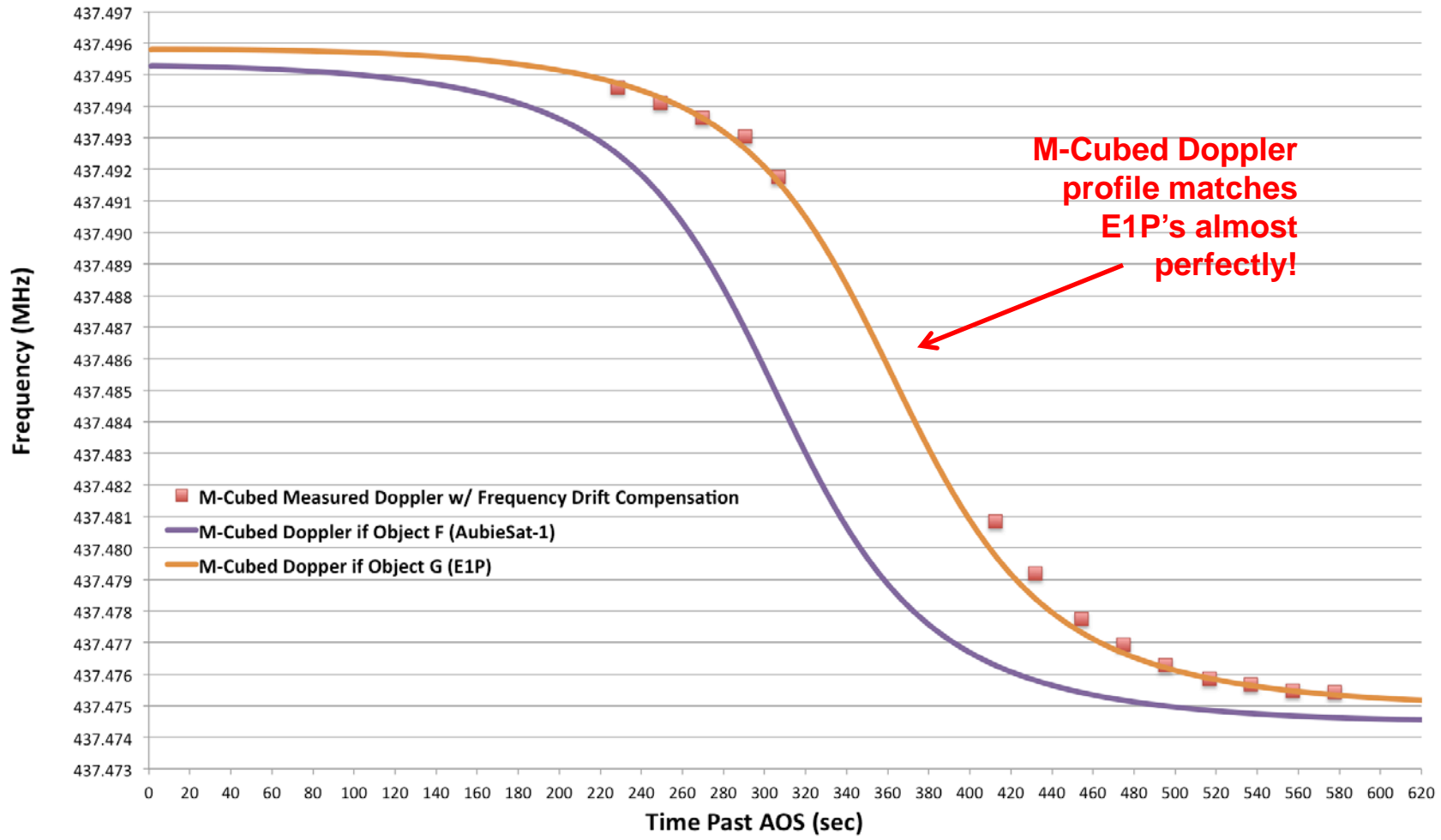




Piecing the Puzzle Together w/ Doppler



M-Cubed Doppler vs. E1P and Aubiesat (12-3-11 Pass @ 2:39 UTC at DK3DWN)





Piecing the Puzzle Together w/ Doppler



How TLEs appeared on Space-Track on December 2nd, 2012

Catalog Number	Common Name	International Designator	Country (Key)	Launch Date	Launch Site (Key)	Decay Date	Period	Incl.	Apogee	Perigee	RCS	Latest Data
37851	DICE 1	2011-061B	US	2011-10-28	AFWTR		97.43	101.71	814	457	0.063	Last Elset
37852	DICE 2	2011-061C	US	2011-10-28	AFWTR		97.43	101.71	814	457	0.159	Last Elset
37853	RAX-2	2011-061D	US	2011-10-28	AFWTR		97.42	101.7	814	457	0.037	Last Elset
37854	AUBIESAT-1	2011-061E	US	2011-10-28	AFWTR		97.41	101.7	814	456	0.03	Last Elset
37855	M-CUBED/EXP-1 PRIME	2011-061F	US	2011-10-28	AFWTR		97.41	101.71	814	456	0.045	Last Elset

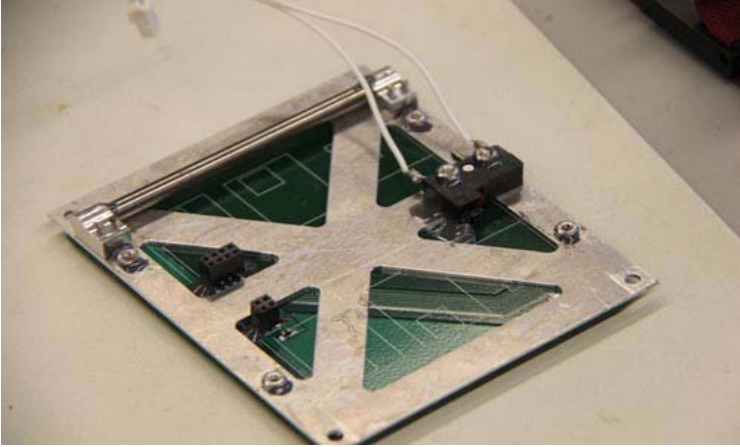
Image courtesy of Mike Rupprecht (DK3WN)



How Could This Happen??

- Several possibilities were investigated (ex: antenna entanglement)
- Strongest evidence currently available suggests magnetic conjunction
- E1P & M-Cubed both used relatively **strong** magnets compared to other 1Us for passive attitude control

Mission	Magnetic Dipole (A-m ²)
E1P	1.856
M-Cubed	1.415
Kysat-1	0.59
AubieSat-1	0.5
XI-IV	0.046



M-Cubed's Permanent Magnet

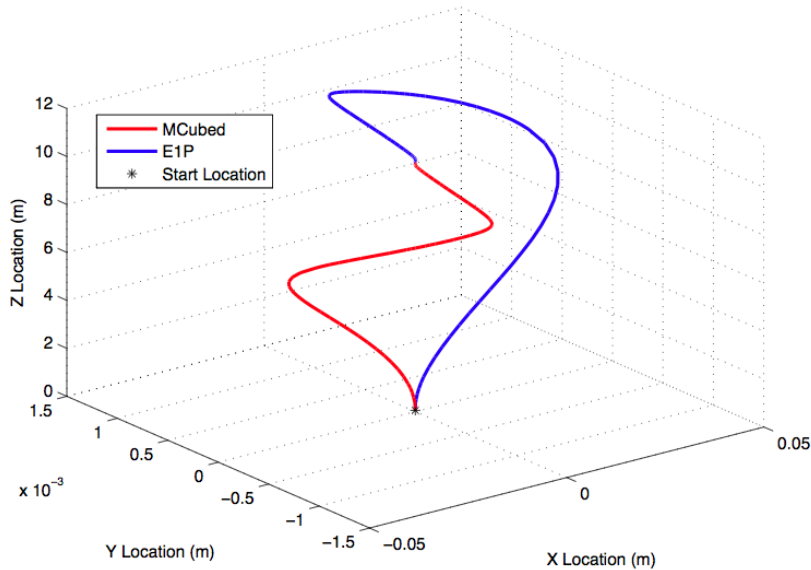
- The magnets used by both sats were NOT facing toward each other in the P-POD – conjunction had to occur AFTER deployment from the P-POD
- Inoperable solar panels on M-Cubed correspond to magnet axis (telem)



Magnetic Conjunction Analysis



- Directed study conducted by John Springmann and Andrew Bertino at UMich to determine if magnetic conjunction possible and, if so, under what conditions
- Developed MATLAB simulation using all available magnet and spacecraft property data
- Results showed that tip-off rotations as slow as 10-20 deg/sec about the Y-axis resulted in conjunction when the separation velocity was less than 5 cm/s (where nominal spring plunger-induced separation is ~15 cm/s)

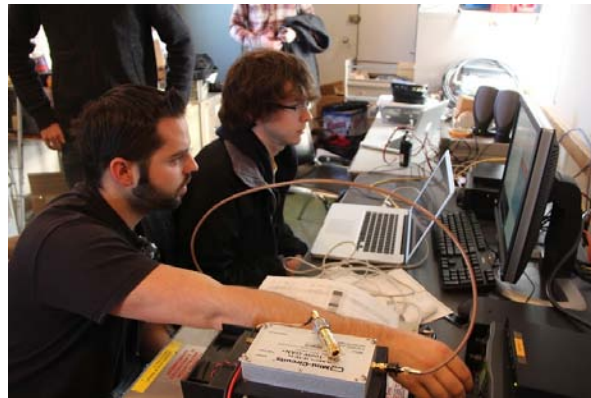
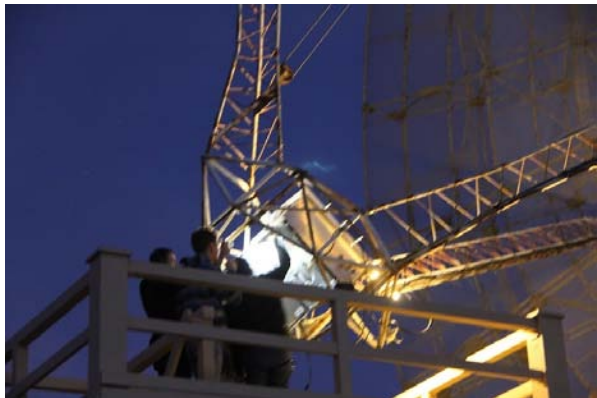




Recovery Operations at SRI



- Unable to command M-Cubed from Michigan ground station due to high noise floor created by M-Cubed electronics on UHF band
- Calculations showed that we needed much greater EIRP than available at UMich for uplink
- Granted access to SRI's 18 meter dish
- Uplink attempts made on nearly every pass over a 3-day period without success despite having sufficient margin over the noise floor





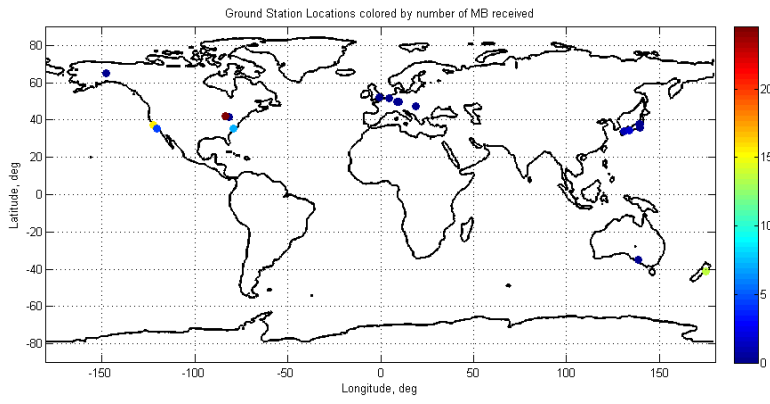
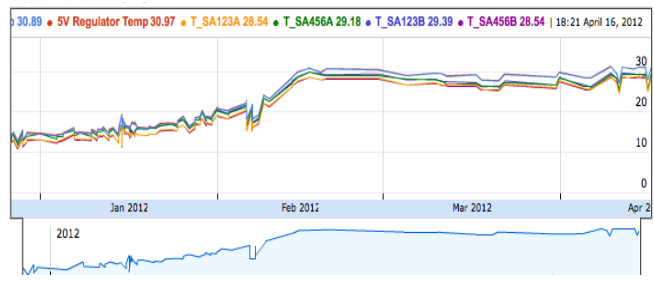
Mission Successes



While currently unable to command, there are many M-Cubed successes to be celebrated...

- Survived a very harsh ride to orbit
- 300+ beacons decoded from around the world with valuable engineering data
- Crosslink telemetry via RAX-2 demo'd
- Continue to remain power positive even with **two** inoperative solar panels
- First US CubeSat missions to effectively demonstrate on-orbit rendezvous!

FCPU		EPS Solar Input Board		EPS Output Board	
CCN 5.3V Current	88.90000 mA	V_1_1REFP	0.98700 V	5.3V Regulator	11.34130 deg C
FCPU 5.3V Voltage	3.30000 V	V_SA1 (+V)	4.83000 V	5V Regulator Temp	12.71700 deg C
FCPU DV Voltage	4.80400 V	V_SA2 (-2)	3.70000 V	Power Battery Current	-14.82700 mA
FCPU Temperature	14 deg C	V_SA3 (-V)	4.57000 V	Battery Warning	0
STD Lias Time	17.117	L_SA1 (+2)	0 A	Antenna Release	0
NumBeacons	72	V_SA4 (-2)	0.00500 A	Antenna Release	2 mA
HighNumActiveTasks1	0	L_SA3 (-V)	0.01800 A	Current	3.80700 V
HighNumActiveTasks0	0	T_SA105A	10.70200 deg C	Cell Voltage	3.87000 V
HighNumActiveTasks16	0	V_SA1 (+V)	1.85000 V	5.3V Current	137 mA
LowNumActiveTasks	4	V_SA5 (-2)	3.45000 V	5V Voltage	17 mA
LowNumProcesses	44	V_SA6 (+2)	4.88500 V	3.3V Current	3.38400 V
LowProcessPID	1.207	L_SA4 (+2)	0 A	Vbat Current	9 mA
LowMemB	81.630	L_SA5 (-2)	0.00100 A	5V Voltage	4.89800 V
FreeMemB	32.812	T_SA405A	9.37300 deg C	Vbat Voltage	8.05800 V
L1	0	EPG Regulator MPPT	Status	0	Reference
L10_RX	1	ADC Reference	0	Reference	0
L10_TX	1	SA2	0	V	0
CCN GPIO MPPT Status	0	T_SA105B	10.51700 deg C		
EPG_ANTENNA_DEPLOY	0	T_SA405B	9.00500 deg C		
		Reset Condition	0		

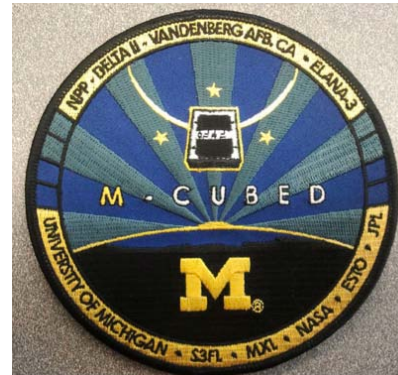




Looking Ahead



- Continue developing magnetic conjunction model
 - Add magnetic field and AubieSat-1
 - Determine minimum magnet strength/separation that does not result in conjunction with low sep velocities
- Cal Poly looking into requirements for next rev of the CubeSat Design Specification for magnet strength and spring plungers constants to mitigate conjunction potential on future launches
- Michigan to attempt uplink over VHF w/ new ground station upgrades
- NASA has approved funds to build a second M-Cubed! Stay tuned!





Acknowledgements



- M-Cubed and COVE Teams
- Garrett Skrobot and the ELaNa Program
- Amateur Radio satellite community, especially Mike Rupprecht (DK3WN), Colin Hurst (VK5HI), and Tetsurou Satou (JA0CAW)
- SRI International, especially Bryan Klofas, Mike Cousins, and Scott Williams
- US Strategic Command's Joint Space Operations Center
- Ehson Mosleh & Dr. David Klumpar (Montana State University)
- Roland Coelho (Cal Poly)

