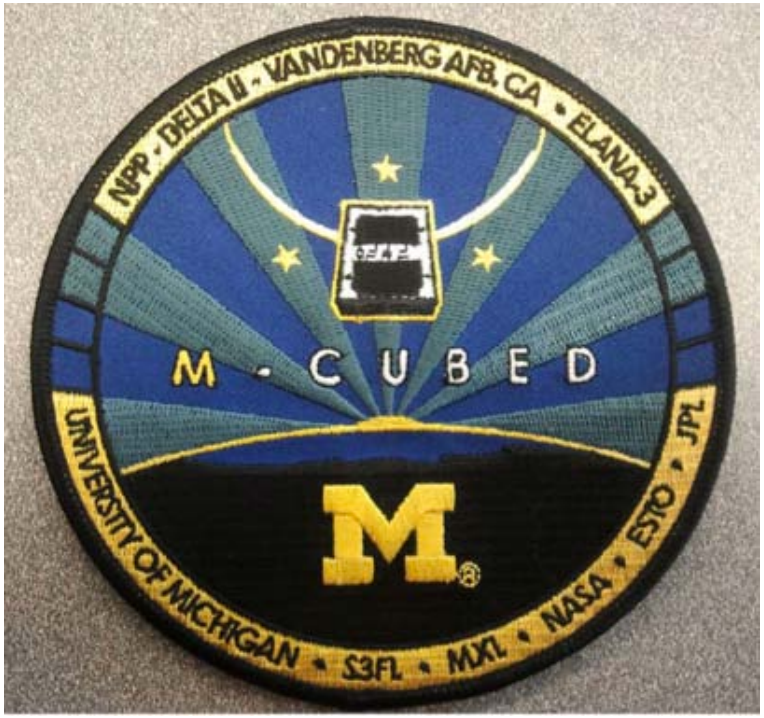
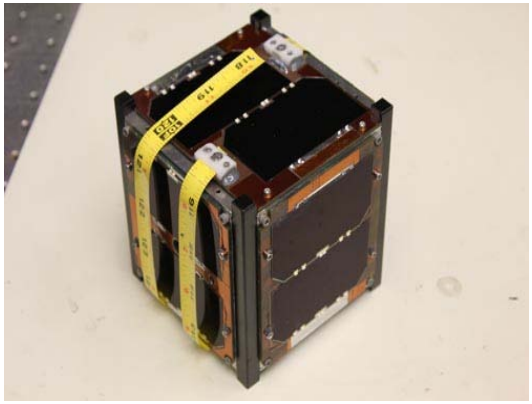
The M-Cubed/COVE Mission





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CubeSat Developers' Workshop
April 18, 2012

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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

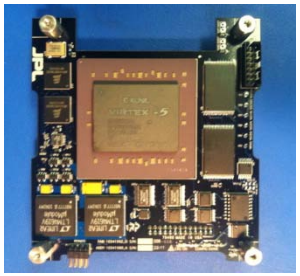
CubeSat Onboard processing Validation Experiment (COVE)

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.

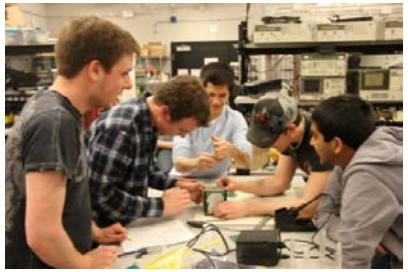
A Solution: Move the first stage of ground processing on-board the satellite in a new radiation-hard-by-design FPGA. This would reduce downlink requirements by *two orders of magnitude*.

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).

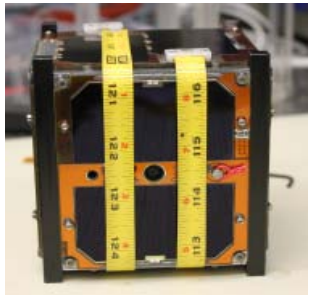
Real-time Onboard Processing for MSPI (AIST, Pingree/JPL)



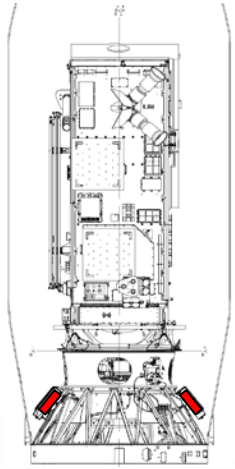
Xilinx Virtex-5QV FPGA



Michigan COVE S3FL Team



COVE Flight Unit

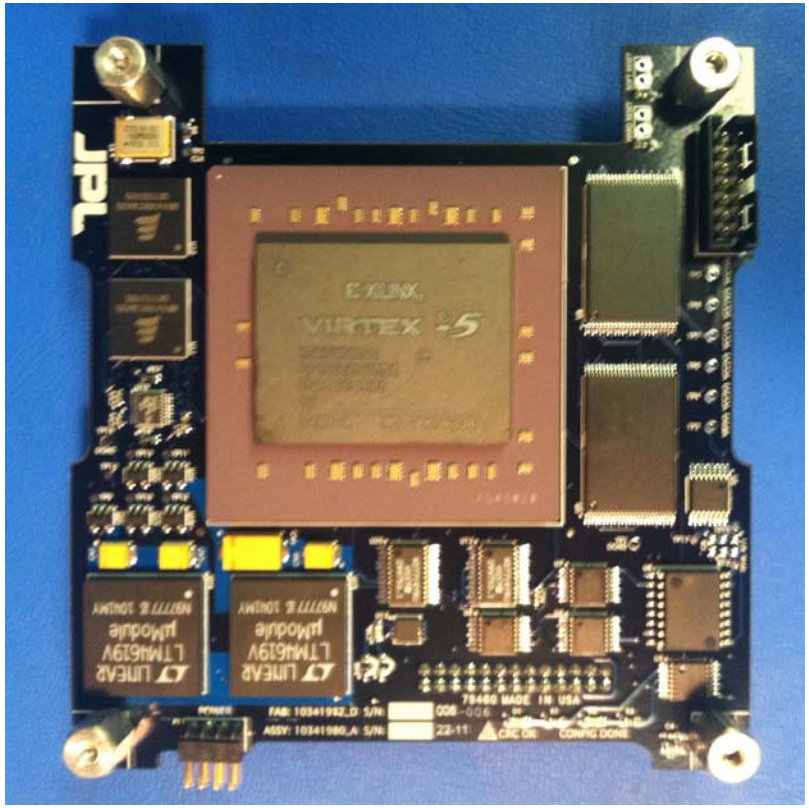


NPP Satellite and P-PODS (in red) on the Struts

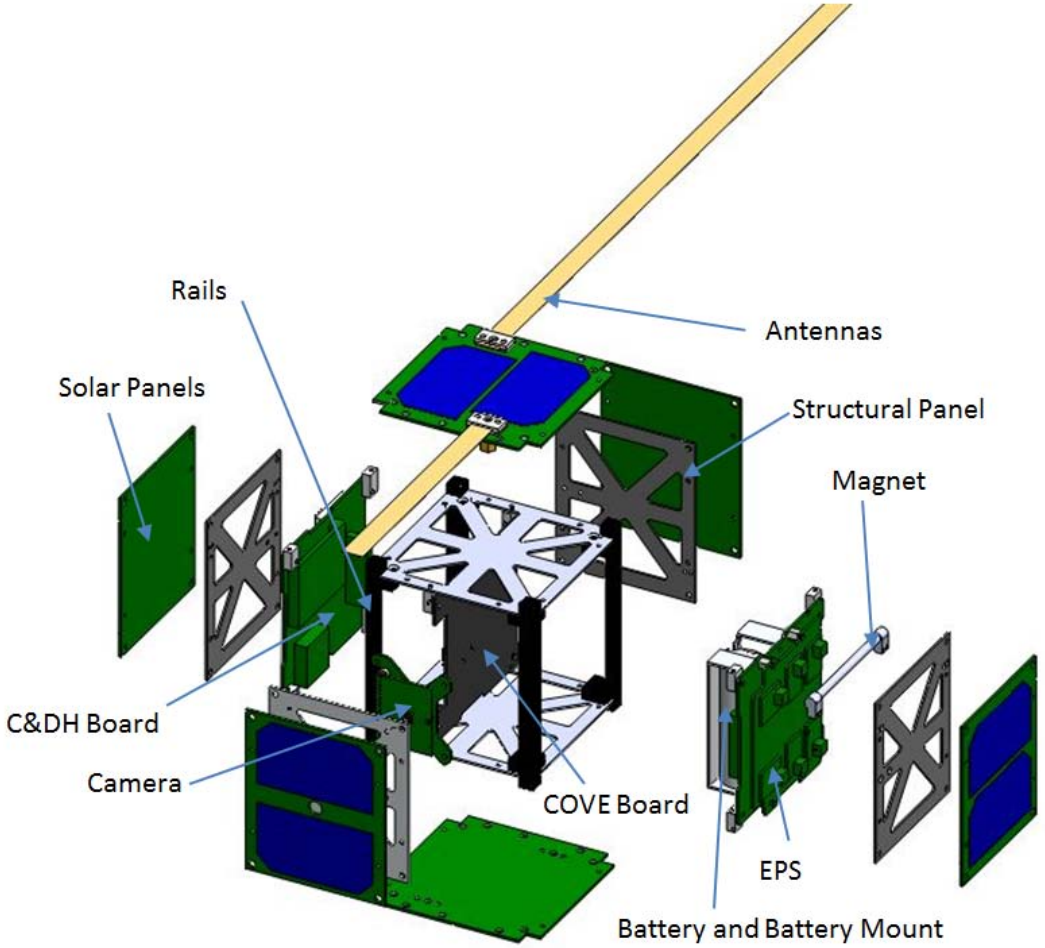
COVE Flight Board with Virtex-5QV

Overview

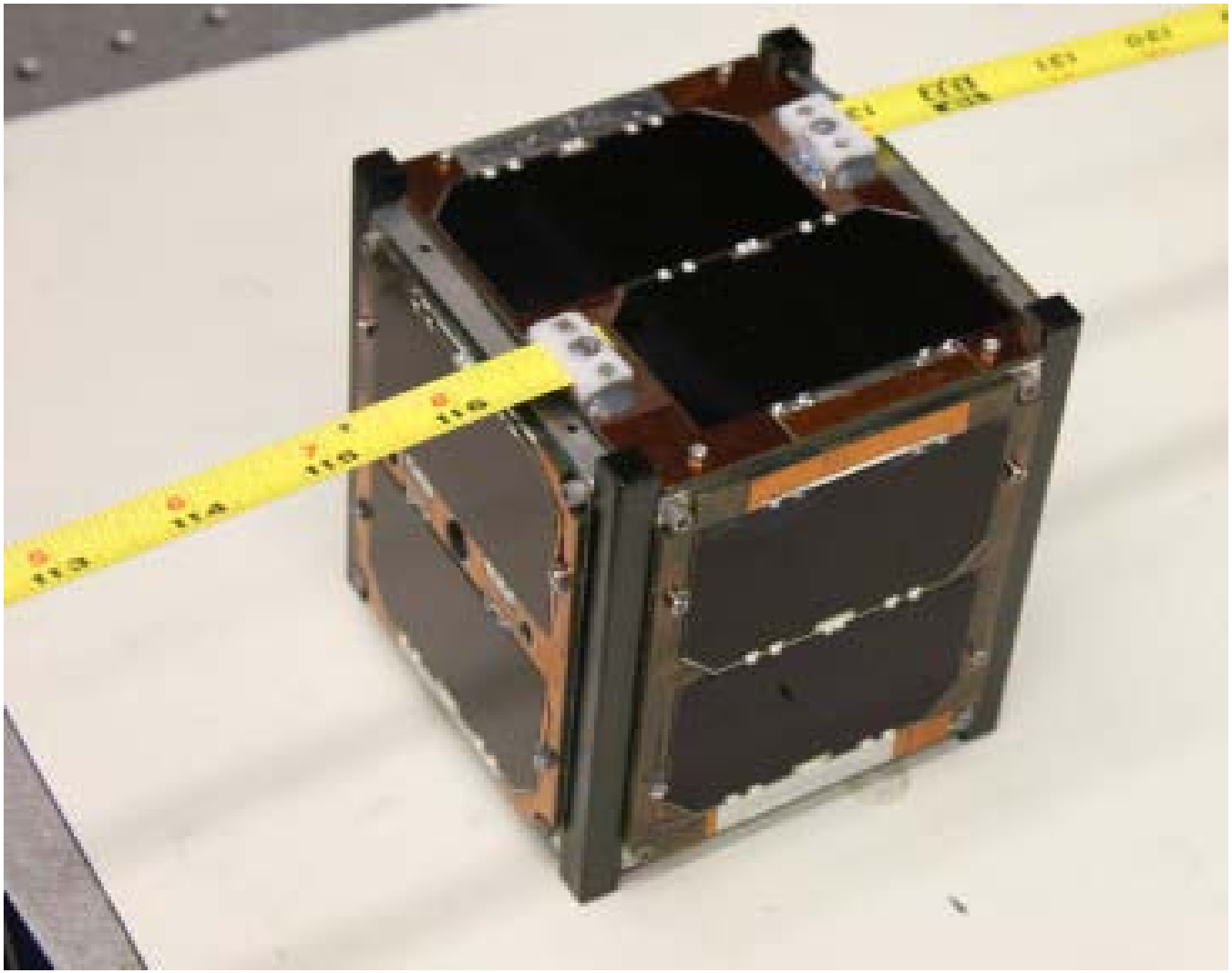
- Fully populated board before and after conformal coating
- JPLs 1st flight installation of 1752-pin CCGA device



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)

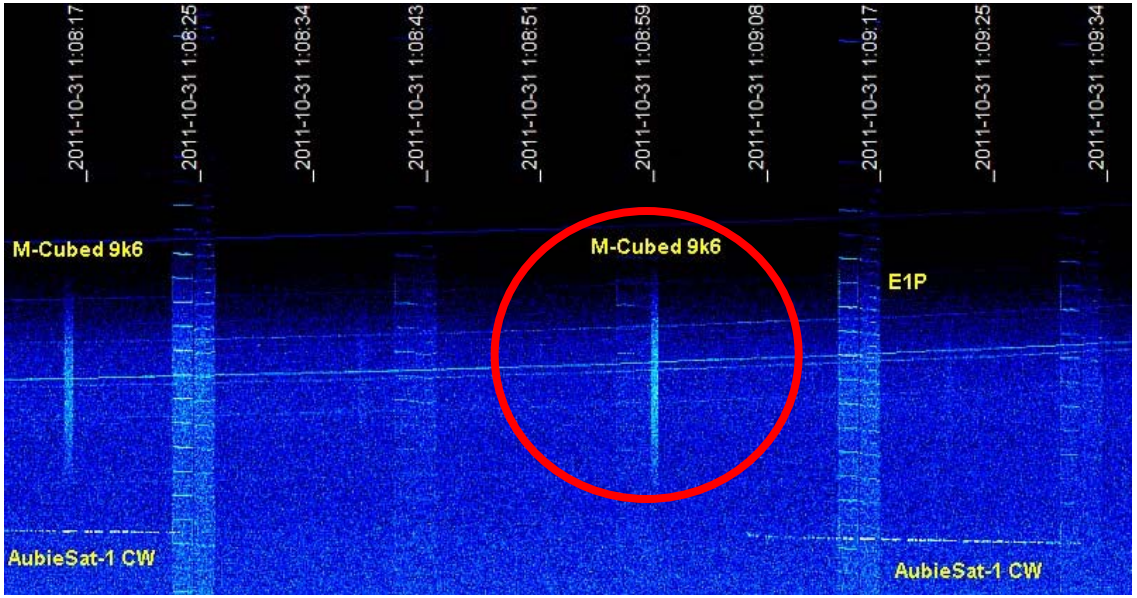
P-POD-2

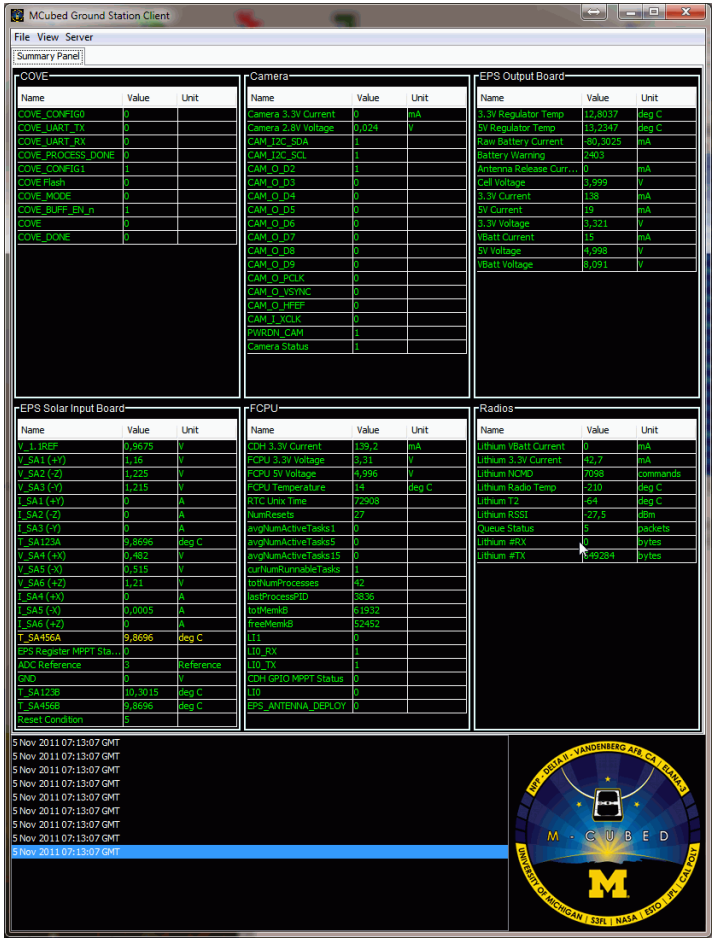
- RAX (Michigan/SRI)

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?

Images courtesy of Mike Rupprecht (DK3WN)

Post-Deployment CubeSat “Lottery”

WHERE IS M-CUBED??

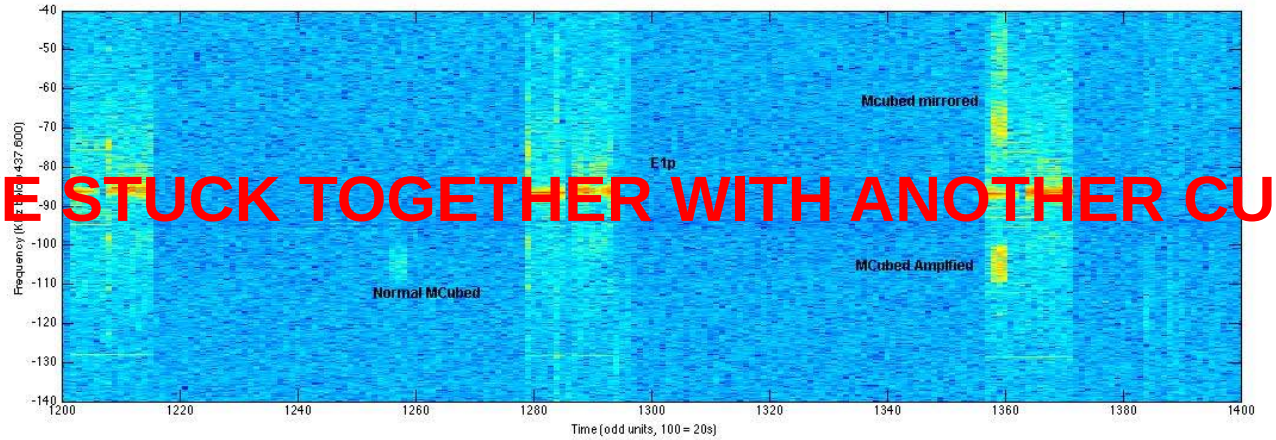
SatID	Object	Launch Date	RCS	ID’d As	ID Date
37850	OBJECT B	2011-10-28	1.698	*NOT NPP Launch Object*	
37851	OBJECT C	2011-10-28	0.136	DICE 1	11.02.2011
37852	OBJECT D	2011-10-28	0.183	DICE 2	11.02.2011
37853	OBJECT E	2011-10-28	0.103	RAX-2	11.02.2011
37854	OBJECT F	2011-10-28	0.047	AubieSat-1	11.25.2011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

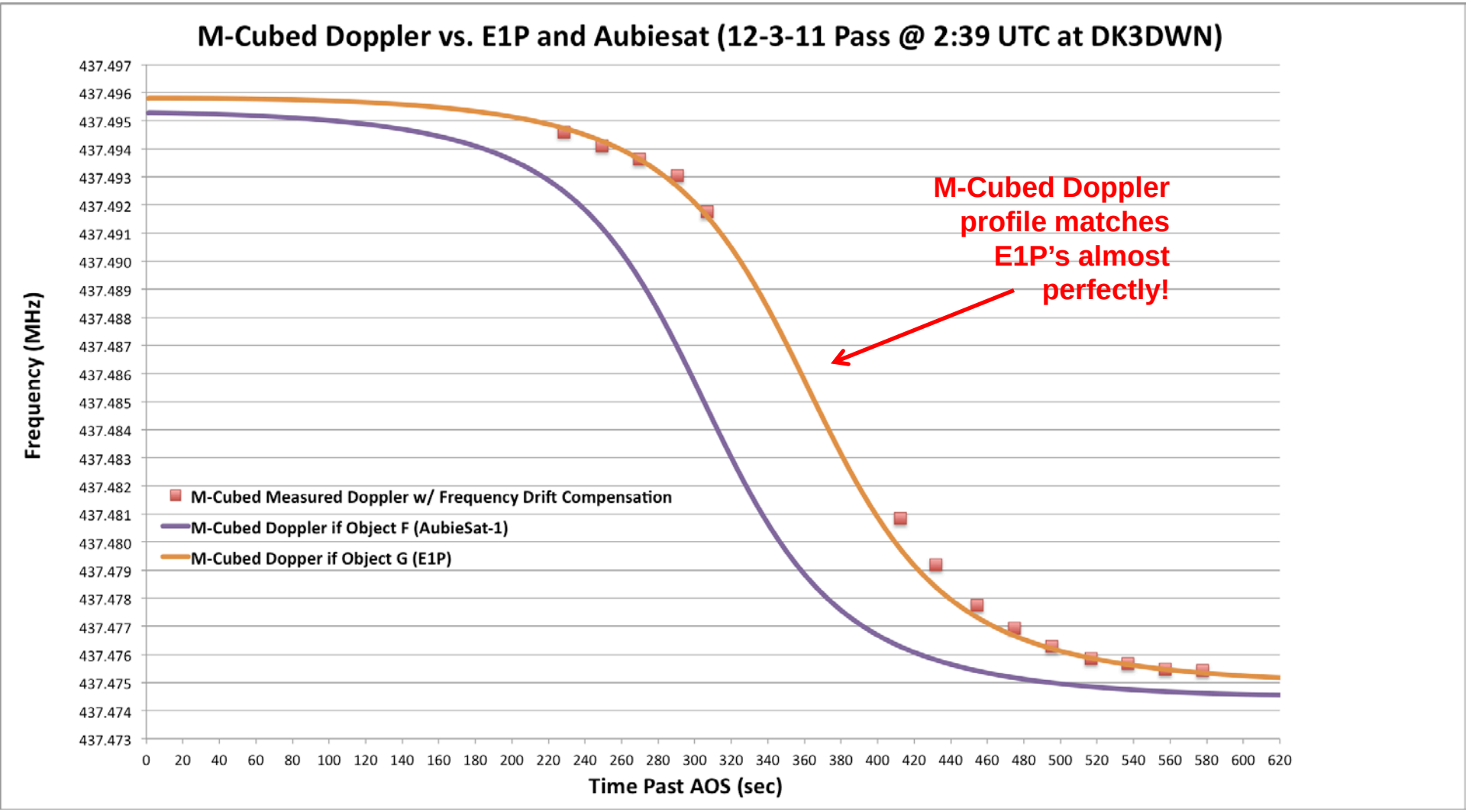
2) Every fourth beacon came in MUCH stronger than the proceeding three, and was overlapping with E1P beacon transmissions

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



Piecing the Puzzle Together w/ Doppler

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

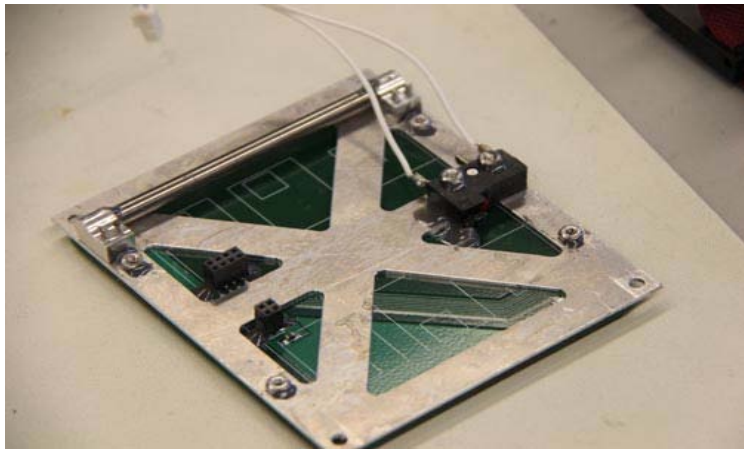
Catalog Number	Common Name	International Designator	Country (Key)	Launch Date	Launch Site (Key)	Decay Date	Period	Incl.	Apogee	Perigee	RCS	Latest Data
37851	DICE 1	2011-061B	US	2011-10-28	AFWTR		97.43	101.71	814	457	0.063	Last Elset
37852	DICE 2	2011-061C	US	2011-10-28	AFWTR		97.43	101.71	814	457	0.159	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

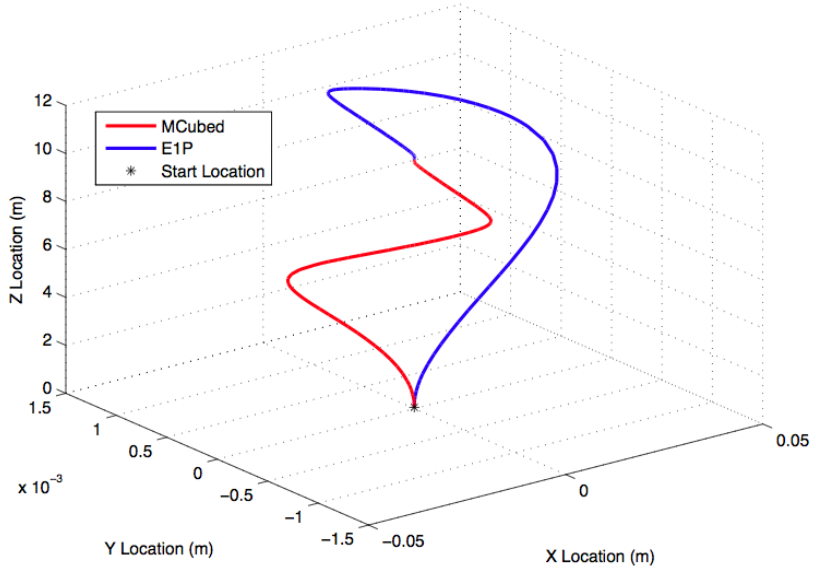


M-Cubed's Permanent Magnet

- 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)

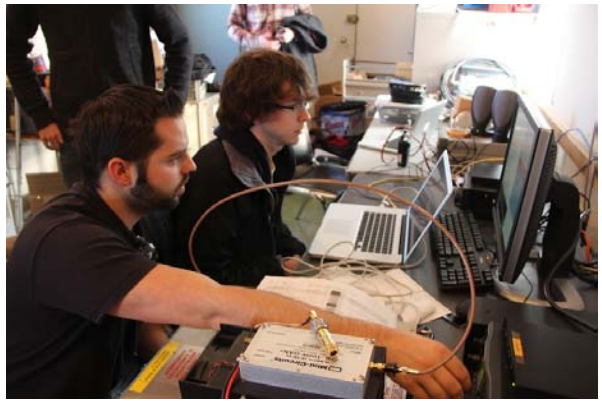
Magnetic Conjunction Analysis

- 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

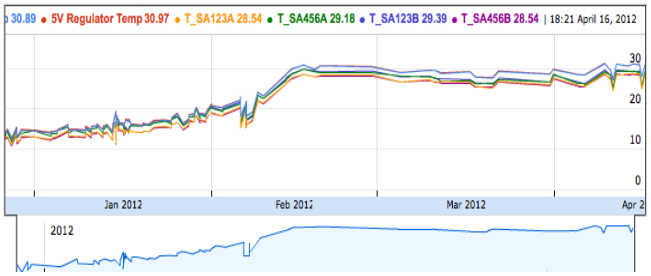
- Unable to command M-Cubed from Michigan ground station due to high noise floor created by M-Cubed electronics on UHF band
- Calculations showed that we needed much greater EIRP than available at UMich for uplink
- Granted access to SRI's 18 meter dish
- Uplink attempts made on nearly every pass over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

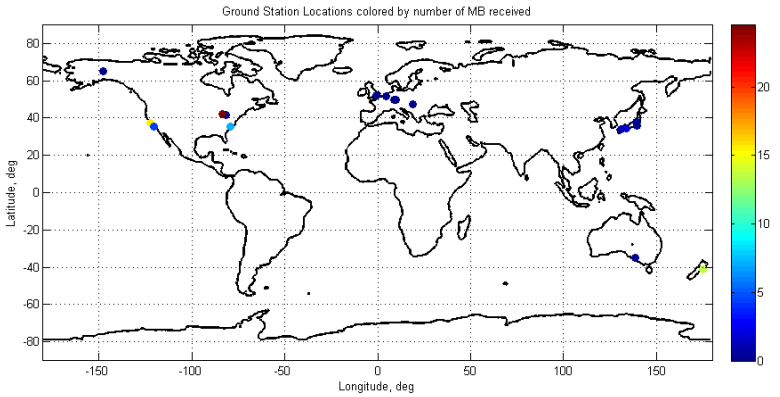


Mission Successes

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 **<u>two</u>** inoperative solar panels
- First US CubeSat missions to effectively demonstrate on-orbit rendezvous!

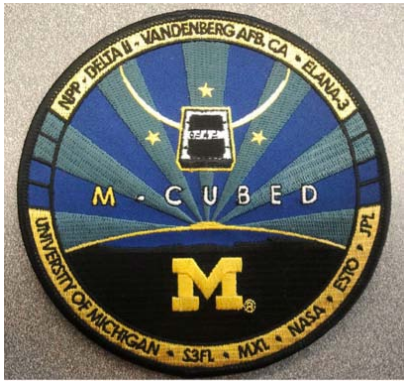




Looking Ahead

- 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!

ESTO
Earth Science Technology Office



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)
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- Roland Coelho (Cal Poly)