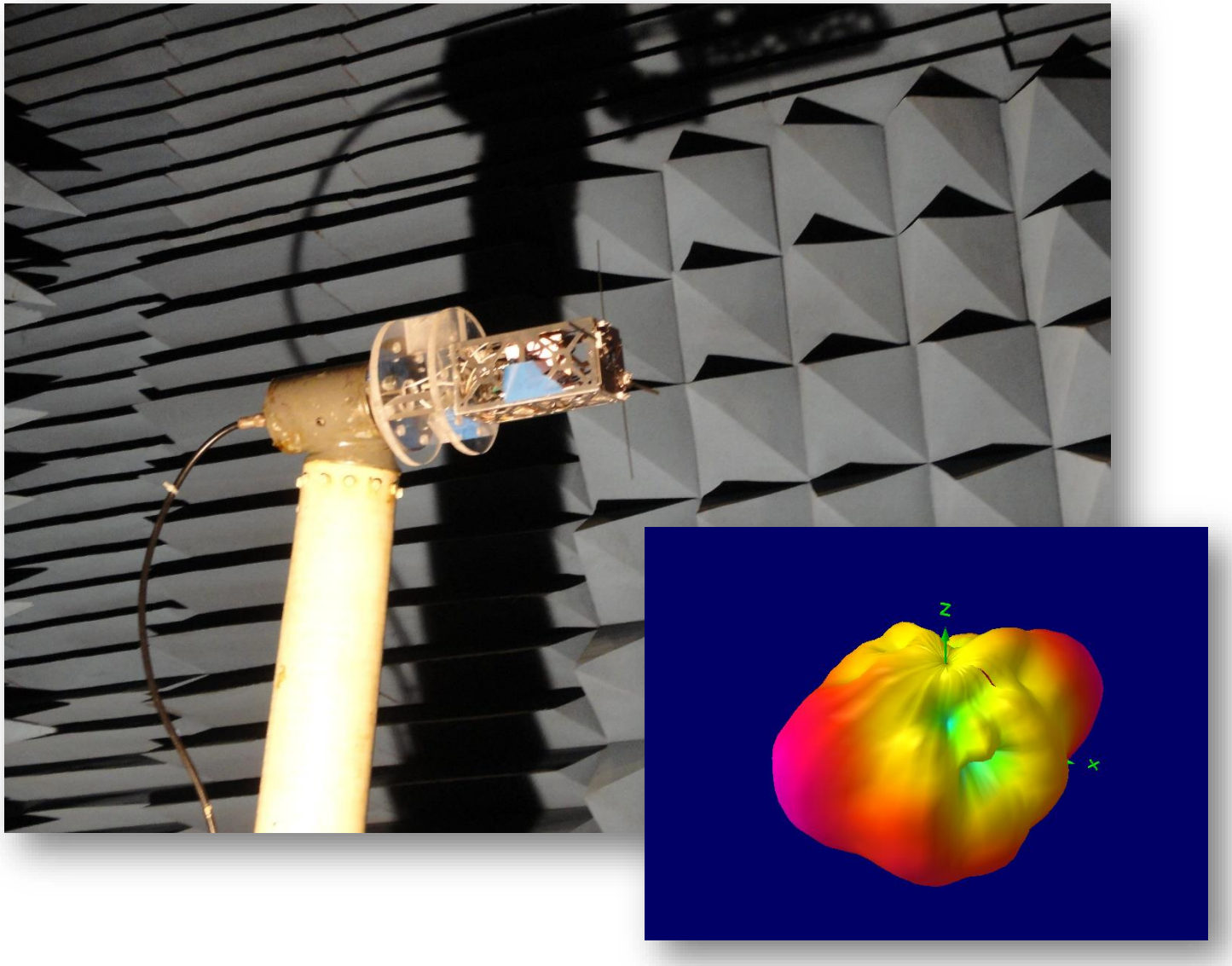
CSUNSat1 Mission Success and Lessons Learned

Overview

- Mission and Goals
- Development
- Mission Achievements
- Successes
- Anomalies
- Failures
- Next Mission



Mission and Goals

- Space qualify new low temperature energy storage system developed by JPL
- Joint project with JPL and CSUN
  - CSUN – 2U spacecraft bus, ground station, mission planning and execution
  - JPL – payload
- Lead students into space careers
- Develop CSUN's capability as a partner with JPL/NASA
- Gather performance data for power, comm and space environment
- Part of CSLI and ELANA programs

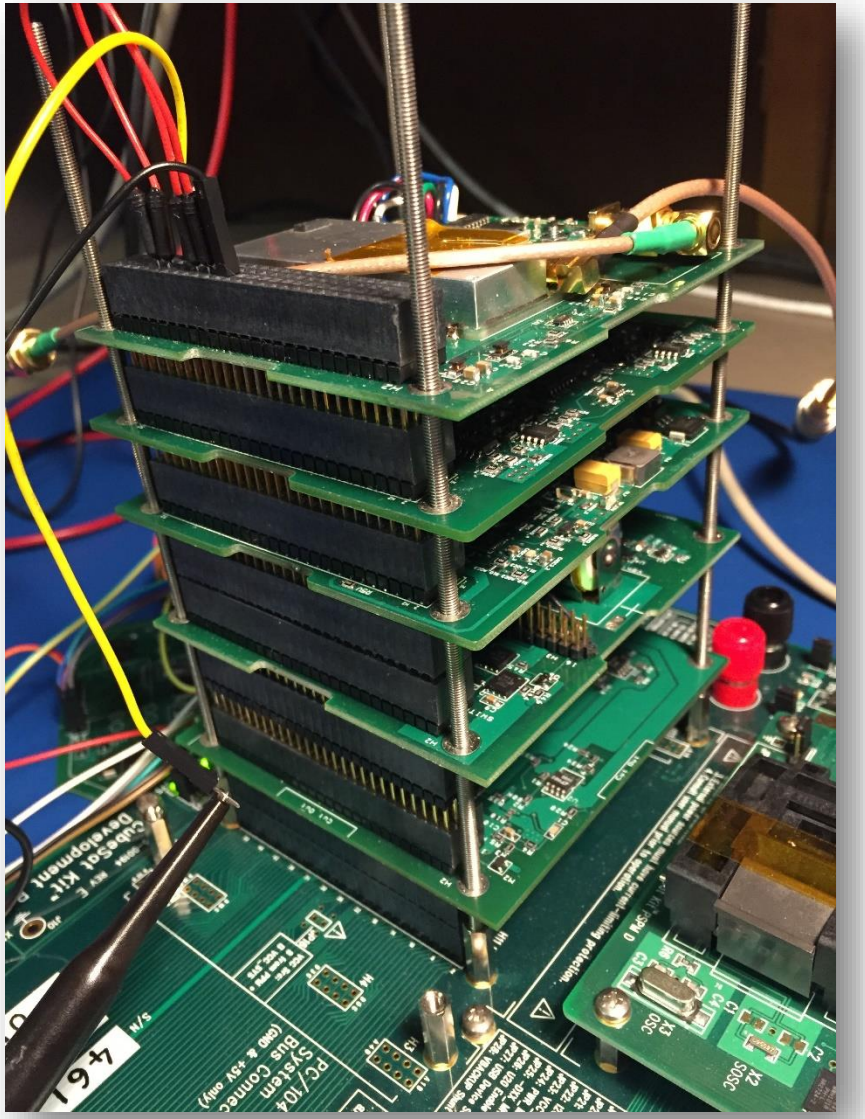
JPL
Jet Propulsion Laboratory

Development

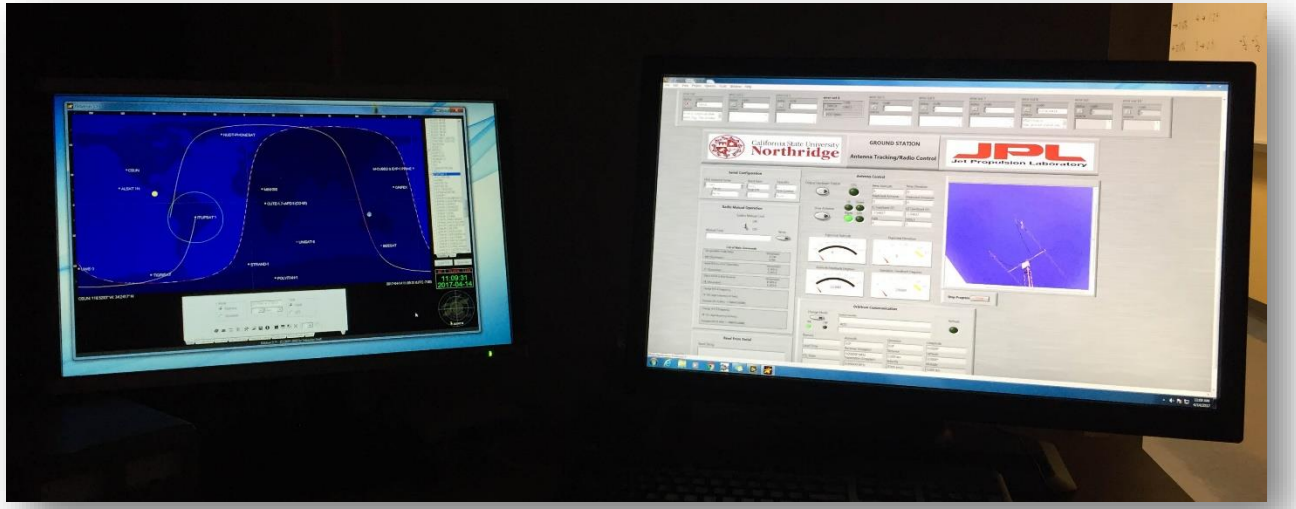
- JPL led by Naomi Palmer
  - With Gary Bolotin and Keith Chin.
- CSUN led by Dr. Sharlene Katz
  - Assisted by Dr. David Schwartz , Dr. Adam Kaplan and James Flynn
- Four years involving 70 students. Over 20 now working in space industry.

Development

- Off the Shelf
  - Pumpkin Kit frame and dsPIC33 processor.
  - AstroDev Lithium II UHF radio
  - Red BEE Beacon
  - ISIS Antenna
- Design and Build
  - Power system to operate off of two different batteries
  - Power distribution and control
  - Sensors and telemetry acquisition for 44 sensors
  - Solar panels for Spectrolab XTJ cells
  - Complete ground station

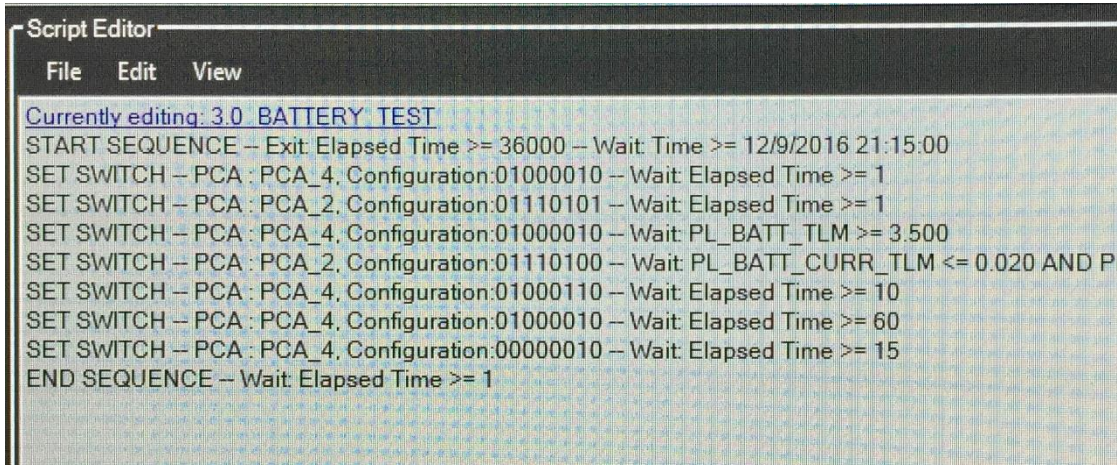


Development



- "Metal Up" Software on Spacecraft
  - State machine – no o/s
  - One interrupt to set flag
  - 40,000 lines of code
  - Communications Protocol
  - Programmable experiments and s/c configuration on orbit
  - Anomaly Detection and Mitigation

- All Original Software for Ground Station
  - Spacecraft Command and Control
  - Telemetry recovery and archiving
  - Create and store experiment scripts for uplink
  - Automated communications during passes



Development

- Testing
  - “Test as you go”
    - Microprocessor and radio to start
    - Almost all tests run through ground station
  - Used “Demos” – major milestones to demonstrate and test certain capabilities
  - S/C completely retested at every demo
  - Engineering model used with solar cell simulator. Ran 24/7 over 18 months.
  - Expanded commands and capabilities
  - Froze design and tested simulated mission for eight months. Longer than planned due to launch delay
  - 1781 iterations of flight software with strict version control

It was the worst of times. It was the best of times…

Development

Mission Planning

- Preplanned mission for each comm pass with contingencies
- Developed and tested anomaly resolution for 38 different anomalies – including ground station scripts.
- Detailed procedures for no comm, no beacon, etc.
- Did months of mission rehearsals with ground station
- Every experiment carried out on engineering model first

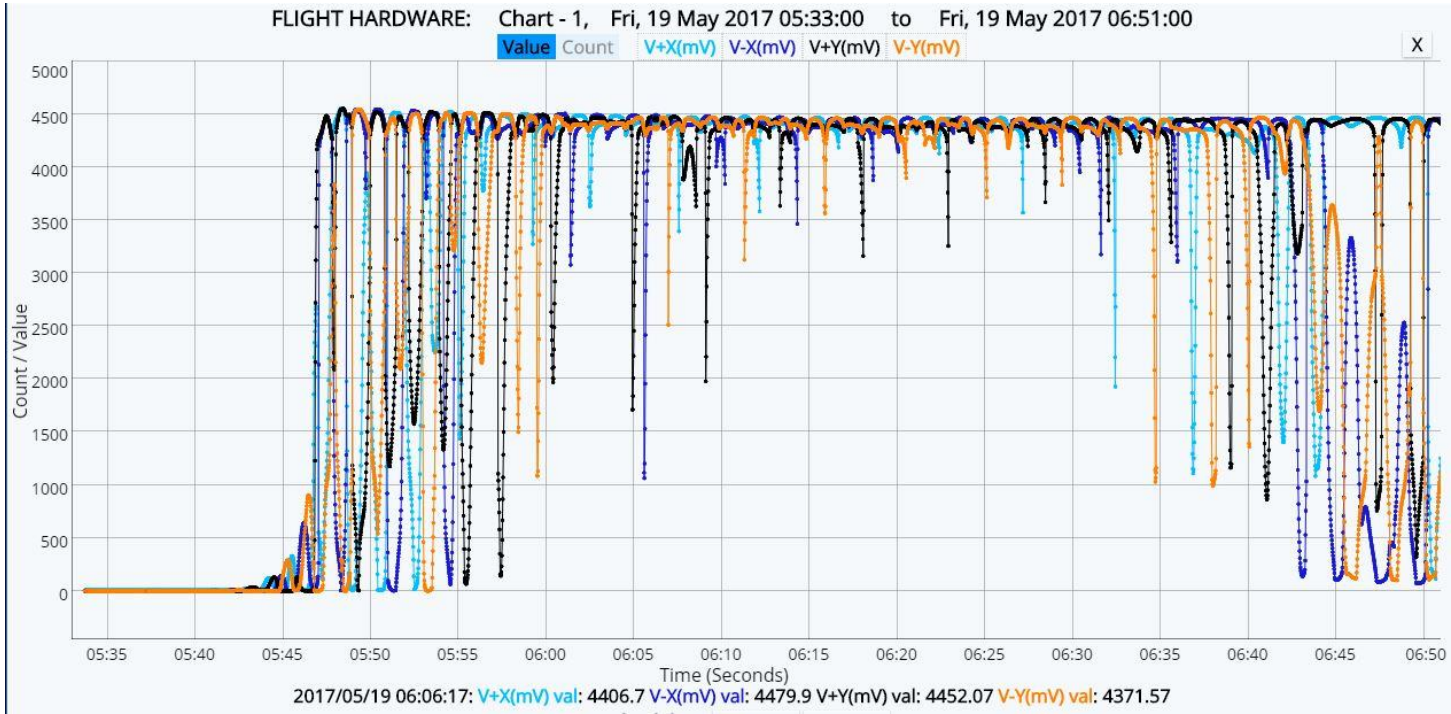
Mission and Achievements

- Launched April 2017.
- Deployed from ISS through
  Nanoracks May 19, 2017

Mission and Achievements

- Saw beacon display on Farnsworth, England WebSDR on second orbit
- Heard beacon and established comm with S/C on third orbit.
  - Beacon indicated we were in “Cube Sad” anomaly state – no comm for over two weeks since deployment.
- Resolved anomaly

  and downlinked S/C health

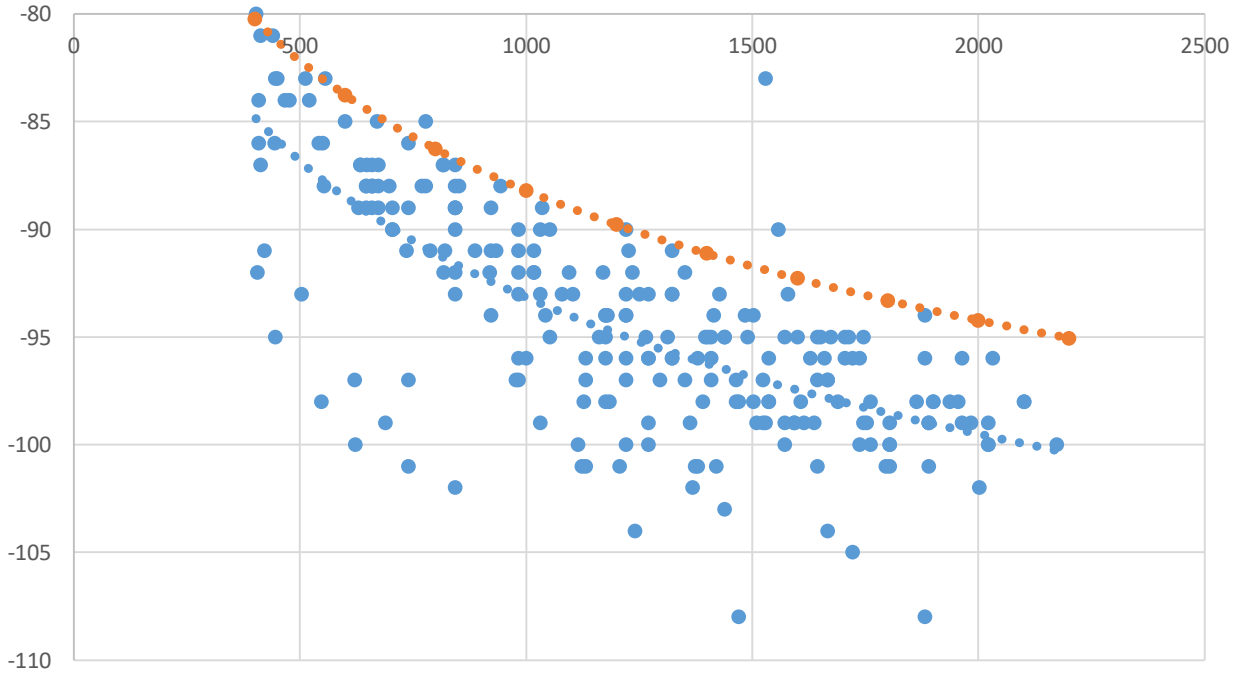


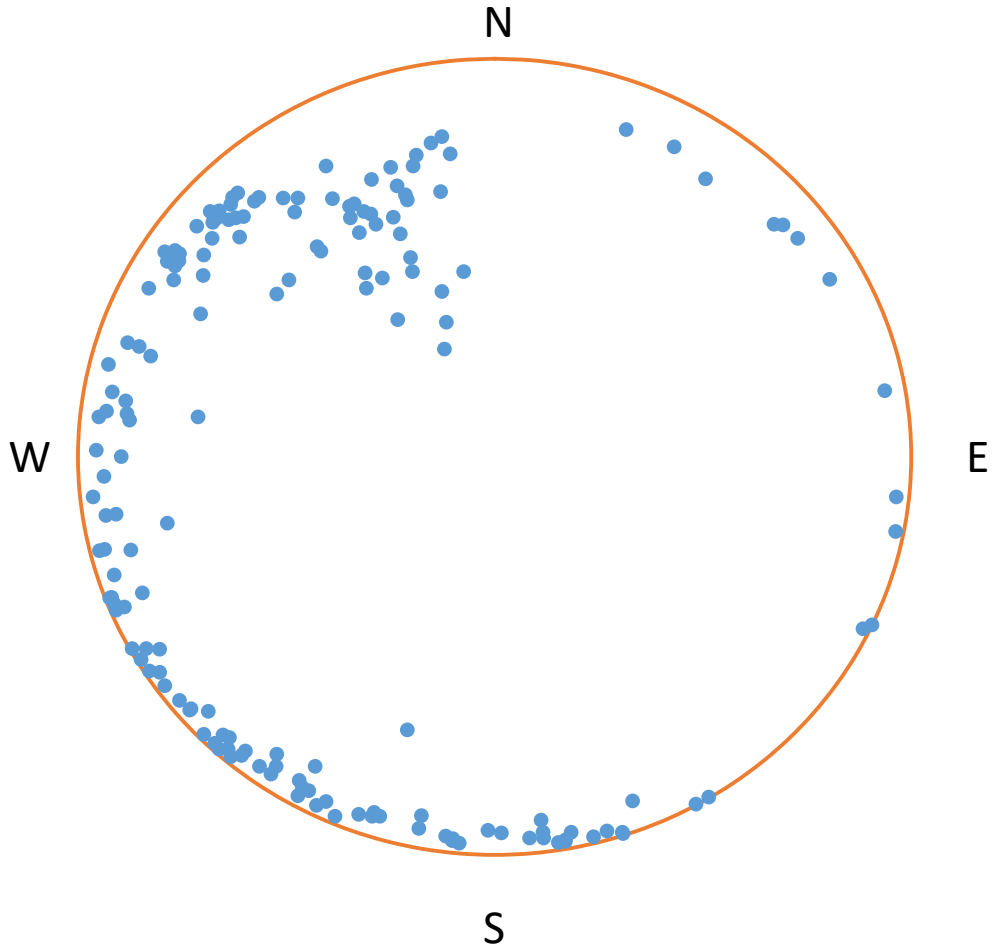
Mission and Achievements

- 12 mission scripts
  - Shortest 15 seconds
  - Longest 25 hours
- Started three days after deployment
- Finished two months later
  - Anomalies interrupted scripts
  - Downlink of data from eight payload sensors, 1Hz, 12 bits: Multiple passes over several days
  - Culminated with S/C running off of JPL Energy Storage System for 25 hours
- Repeated some experiments 2-3 times to determine ageing of system until May 2018

Successes

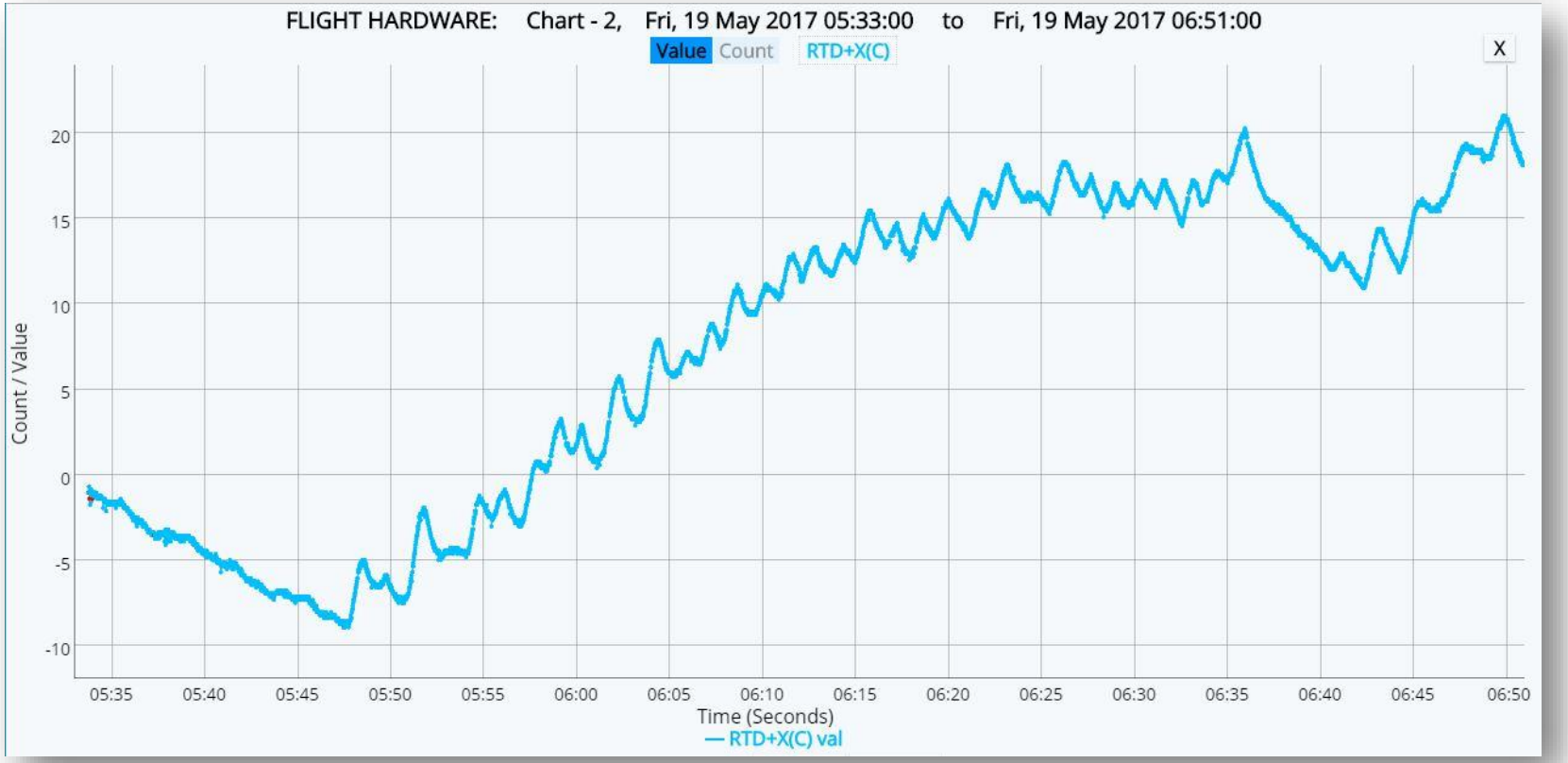
- Communications accessed S/C horizon to horizon
  - S/C antenna system worked despite tumbling
  - Validated prediction of comm performance
  - G/S ran remotely
- 16 Megabytes downlinked error free





Successes

- Temperature model of S/C validated
- Valuable data on conditions in LEO obtained



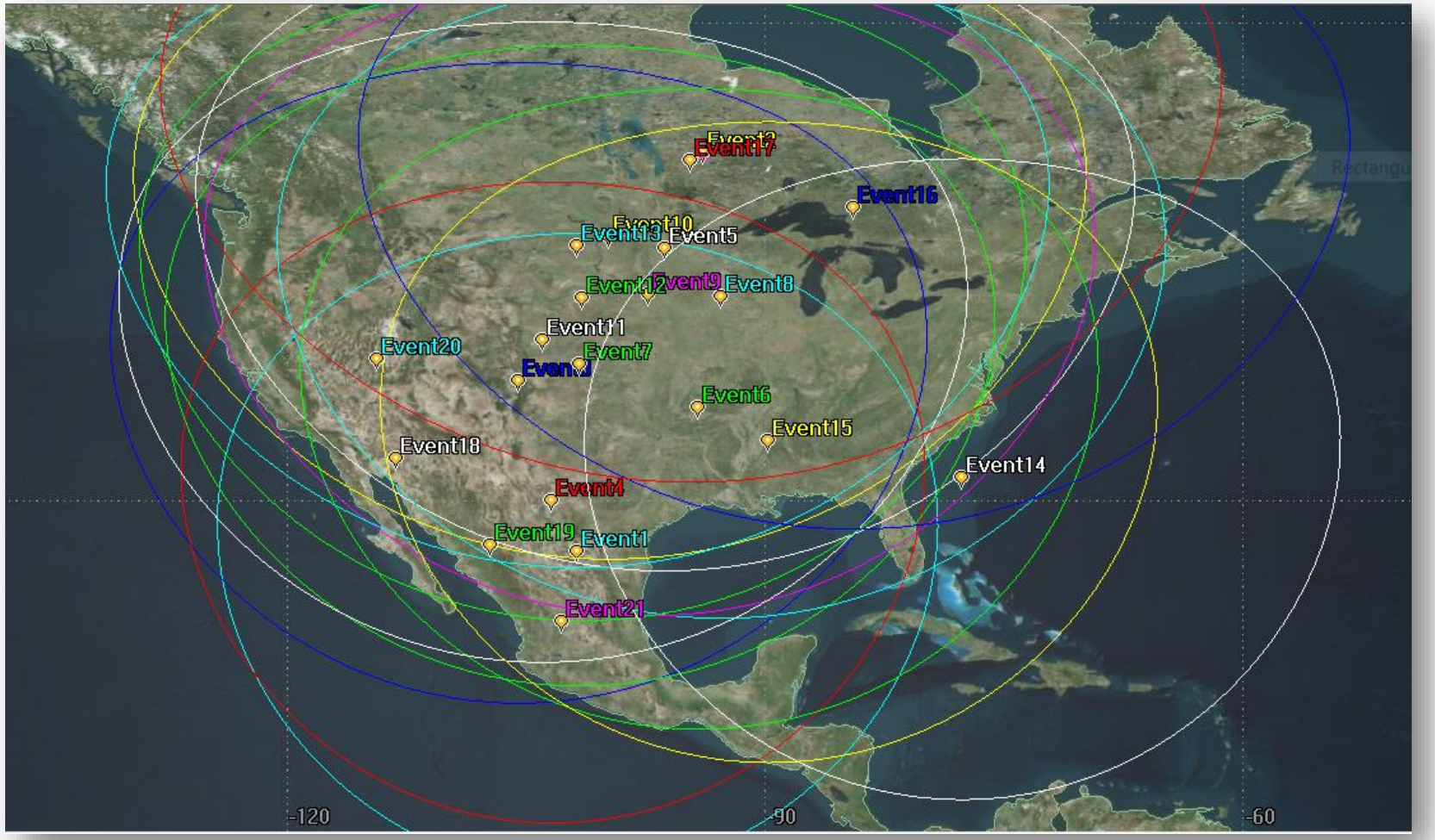
Successes

- Power System able to switch between two different energy storage systems
- Beacon – invaluable with remote WebSDR sites
- “Saw” Eclipse

Anomalies – “Cube Sad” Anomaly

- Triggered if S/C has not had comm with ground 14 days into mission
- Only anomaly not tested before flight
- Mitigation: reconfigure radio and internal interface with radio
- Mission “started” as s/c was flashed with final software five months before deployment
- Led to race condition
  - 1.5 second window in race condition that allowed s/c to be reset and comm attempt to be made
  - S/C contacted on third comm pass and anomaly resolved

Anomalies – Central US Anomaly



Multiple processor address errors occurring only on passes over US.

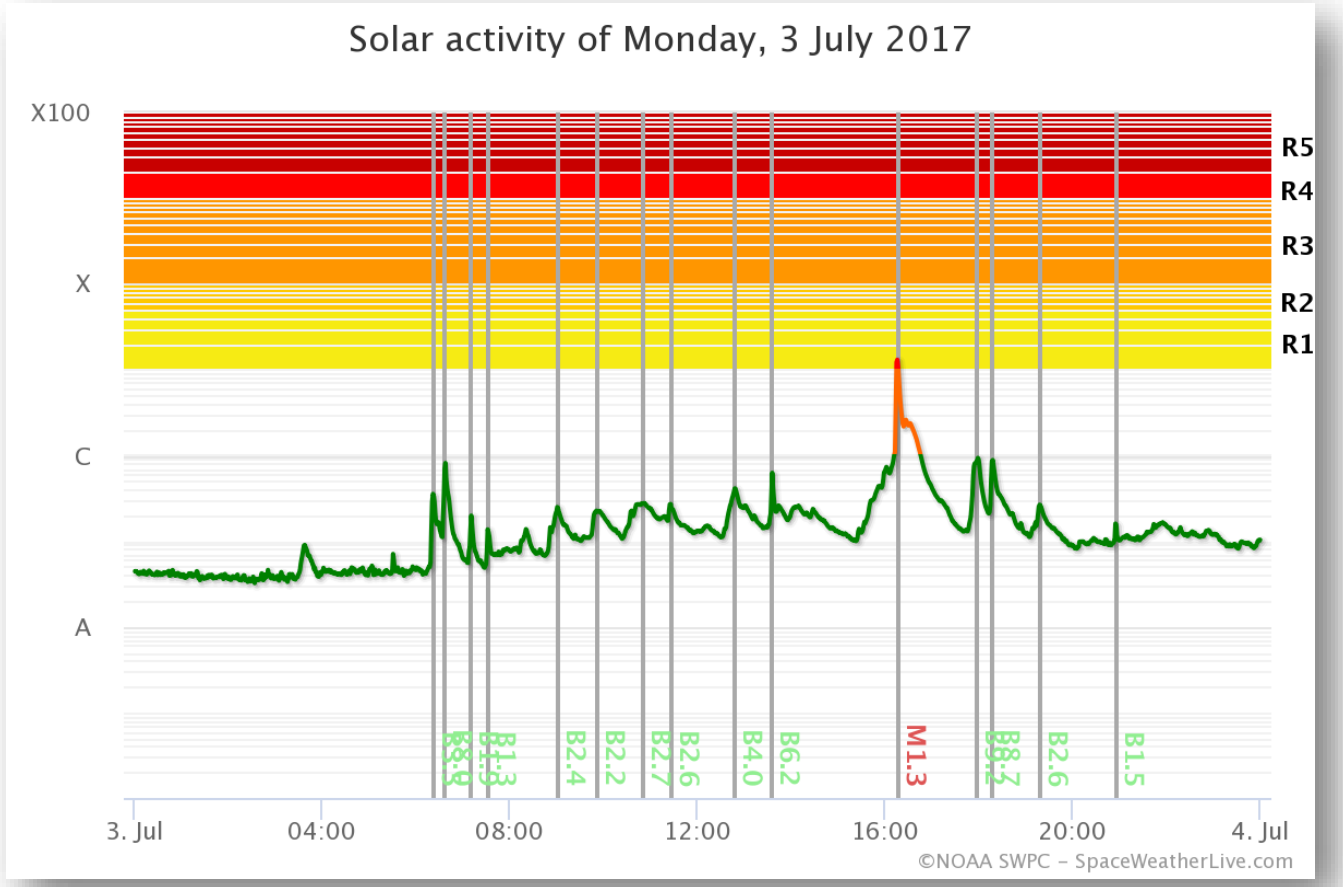
Anomalies – Central US Anomaly

- Comm related - radio only external sensor to affect processor
- Lithium II radio has 100 kHz bandwidth
- Only correlated with ground – not with other satellites
- Must be sending AX.25 packets for radio to react
- More common during daytime over central US

- Suspects
  - Terrestrial signal – curious satellite fan?
  - Unable to duplicate with engineering model
- Resolution: Change uplink frequency

Anomalies – You Need a Full Set of X-Rays

- Space Weather Effects
- Flash Memory Erased during M1.3 Flare
  - Slowly recovered 90 % over several days
  - Repeated several times
  - Possible cause of ultimate loss of comm in May 2018

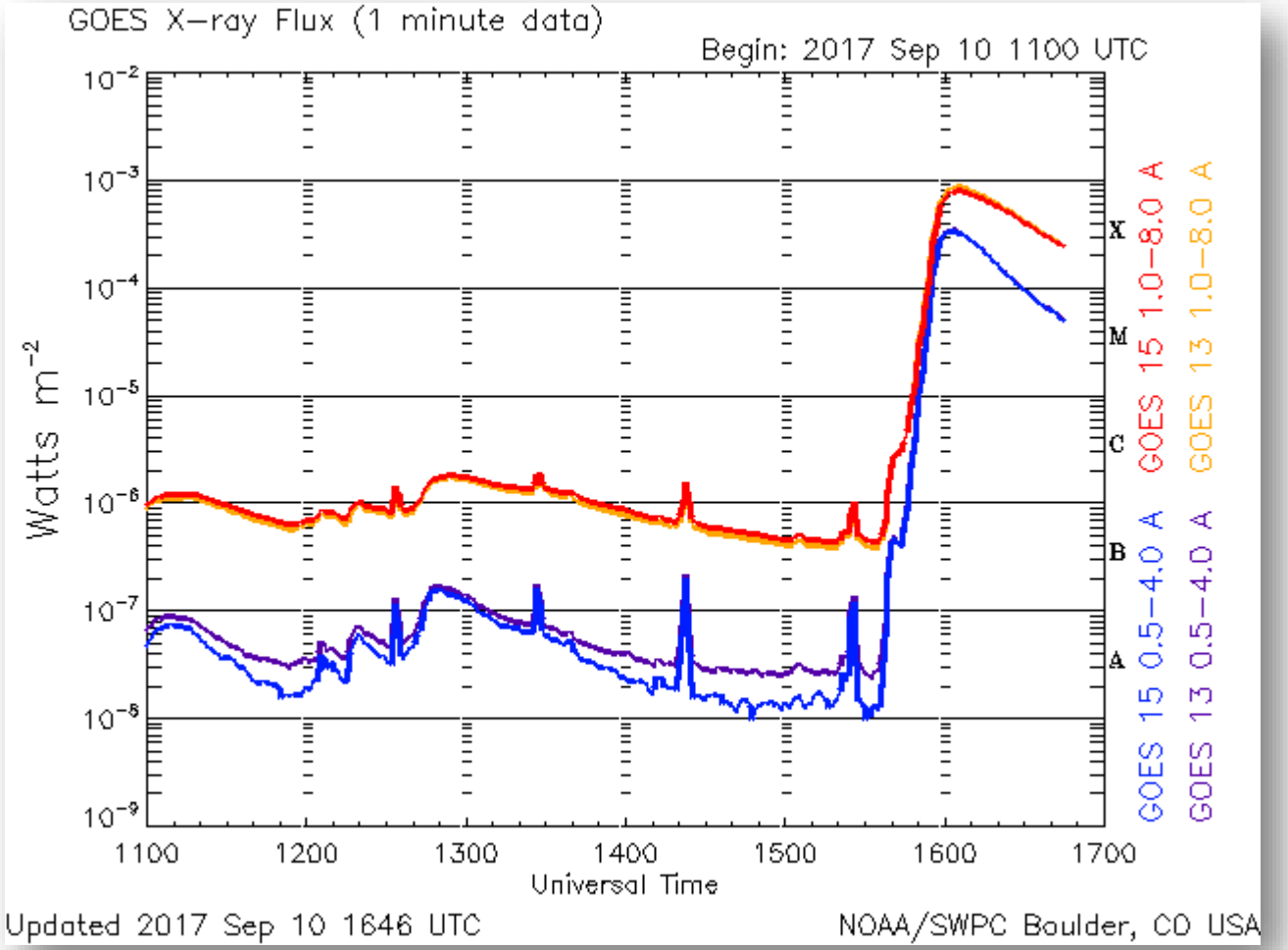


Anomalies – You Will Need a Full Set of X-Rays

- SD Card Failure due to X8.9 flare

  Permanent Loss of SD card

  SD card used was not “best” quality



Anomalies – You Will Need a Full Set of X-Rays

Possible Cause for Radiation Anomalies:

- Design of S/C to keep heat away from payload led to removal of 1.25 mm aluminum end cap just below processor.

- Only 1 mil of copper between processor board and space

- Severely degraded radiation protection

S/C Failure

- Series of work-arounds allowed further experiments.
- S/C clock failed on April 23, 2018
- Unable to open link with s/c after May 5, 2018.
- Spacecraft radio responded to pings until May 18, 2018
- Pings indicated radio was being repeatedly reset – clock failure led to repeated attempts to reconfigure radio due to s/c believing no comm for more than 36 hours
- No response from s/c after that…

Lessons Learned

- State Machine allowed rapid diagnosis of complex anomaly conditions
- Morse Code Beacon allowed monitoring of s/c through remote receiver sites and determining anomaly conditions
- Command and experiment scripts successful
- Communications, power and thermal models work
- Unwise to compromise radiation shielding – but with an X8.9 only hope is to be on the other side of the earth
- Ability to return s/c to initial state (not just reset) vital

Lessons Learned

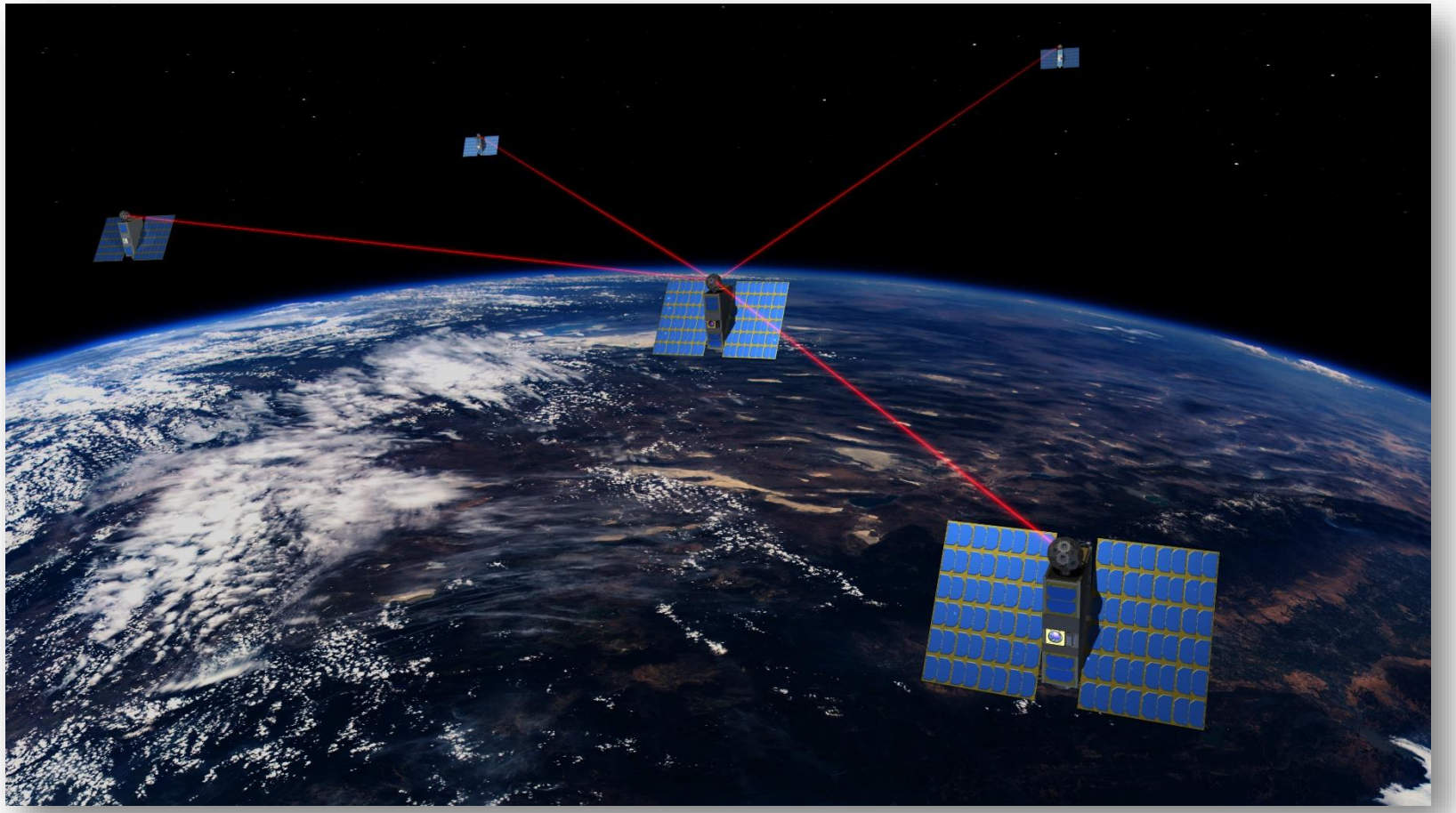
- Engineering Model invaluable
- Need to include method of power cycling entire s/c
- Anomaly resolution procedures and rehearsals essential
- “End to End” Testing tests entire system
- Work with comm system as soon as possible
- Possible to work in creative redundancies
- Perform only as much anomaly mitigation as necessary automatically
- Testing and more testing

Lessons Learned

- Partnering with experts – priceless. Thank you, JPL!
- Multi-disciplinary teams essential
- Document and pass it on

Next Mission

ISOC Laser Satellite Communications System - Dr. Jose Velazco at JPL.



Next Mission

SHARLENE 1

www.csun.edu/cubesat james.flynn@csun.edu

Jet Propulsion Laboratory