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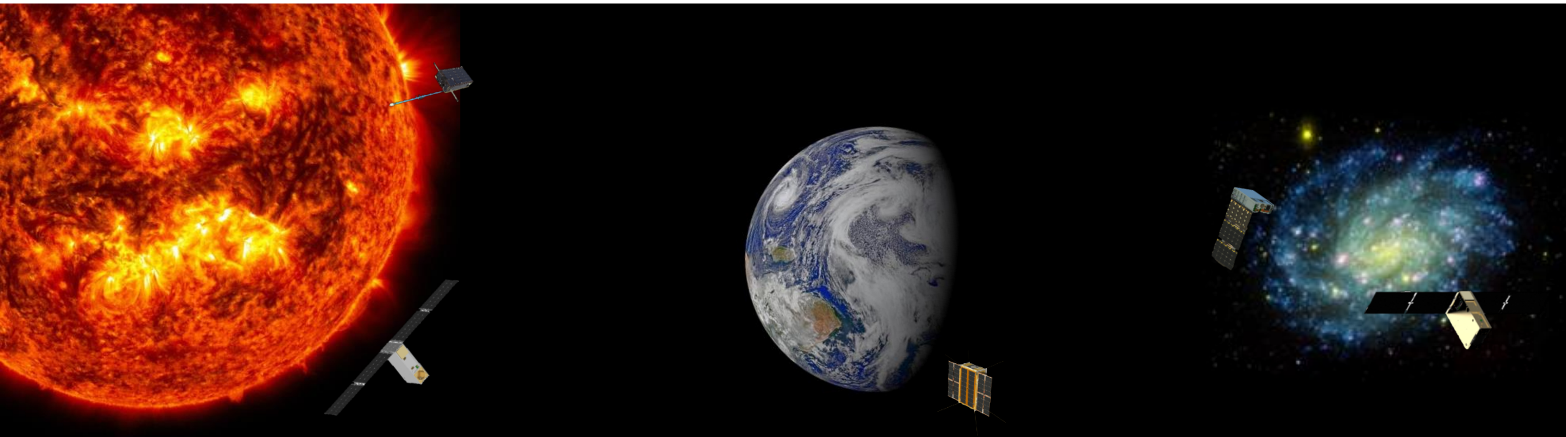

GTOSat: Radiation Belt Dynamics from the Inside

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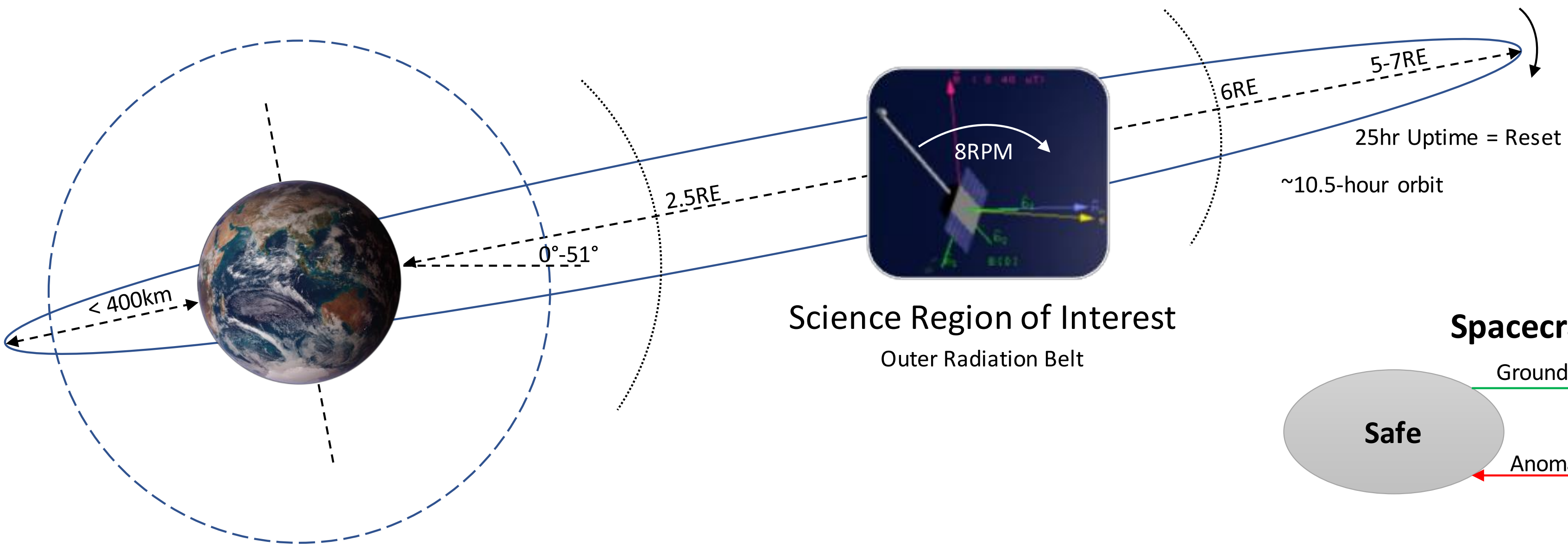
GTOSat

Aerospace • NASA GSFC • U of Iowa

Mission Overview

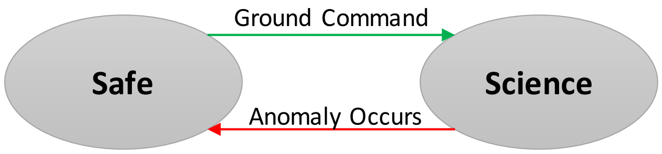
- Advance our quantitative understanding of acceleration and loss of relativistic electrons in Earth's outer radiation belt
- Highly elliptical geo-transfer orbit (GTO) with nominal apogee near 6.6 earth radii geocentric
  - Beyond Van Allen Probes
- Concept of Operations
  - Always sun pointing and spin stabilized (8RPM)
  - Near Space Network (NSN) Direct-to-Earth (DTE)
  - Space Relay - Demand Access System (SR-DAS)
  - Two spacecraft modes, safe and science



Science Region of Interest

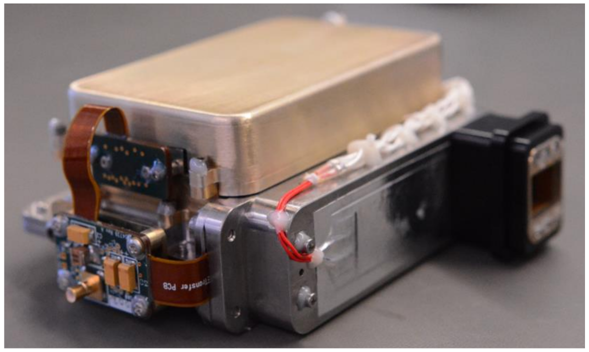
Outer Radiation Belt

Spacecraft Modes

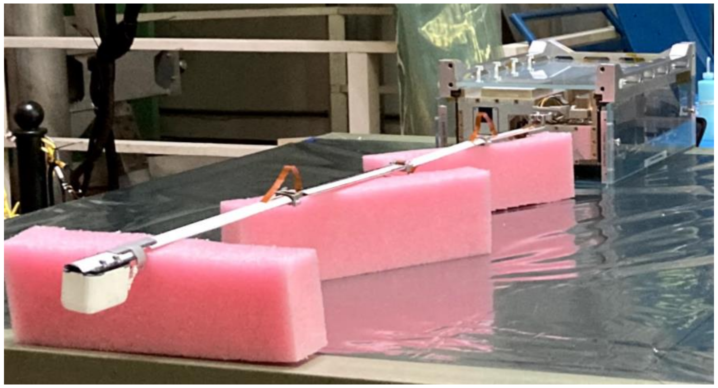


Science Instruments

- Relativistic Electron Magnetic Spectrometer (REMS)
  - Developed by The Aerospace Corporation
  - Electron instrument is a miniaturized version of MagEIS onboard the Van Allen Probes with 9-pixel detectors measuring 100 keV to > 1 MeV
  - Proton detectors based on the micro Charged Particle Telescope from the AeroCube-10 with 2 detectors measuring <650 keV to > 7 MeV
  - Calibrated at The Aerospace Corp. using a series of radioactive sources and a beta radiation spectrometer



- Fluxgate Magnetometer (FMAG)
  - Developed by NASA GSFC's Solar System Exploration Division
  - Designed for satellite-based vector magnetic field measurements in Earth's magnetosphere
  - Modified version from MAVEN, Juno, and Parker Solar Probe missions
  - Sensor on one-meter extendable boom designed by FMAG team
  - Testing occurred at the NASA GSFC magnetic calibration facility

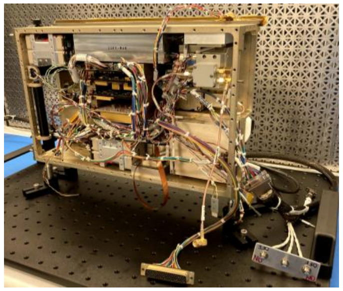


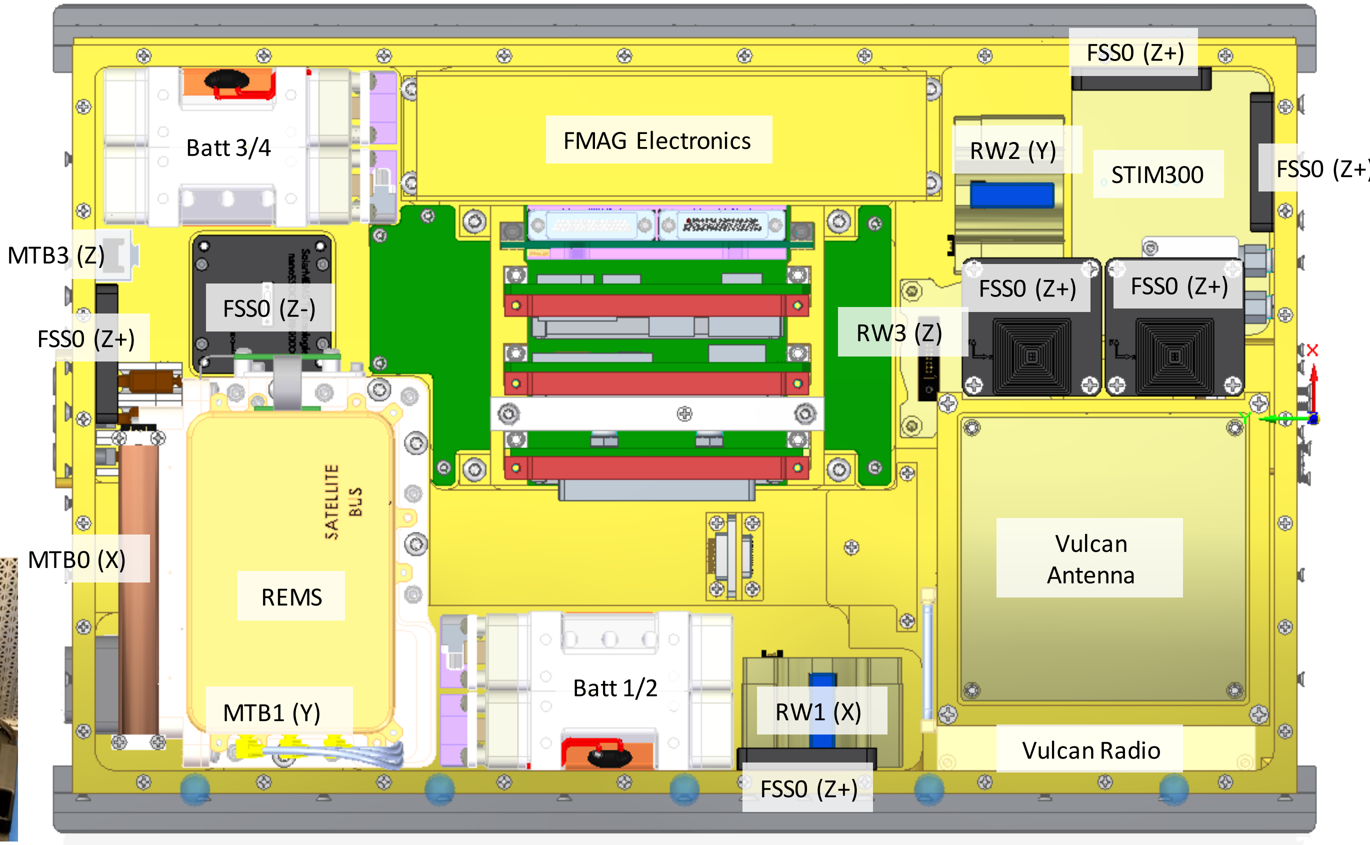
Geo-Transfer Orbit Complexities

- Attitude Determination and Control
  - Enough control authority?
- Launch
  - Available? 25-year deorbit analysis? Conjunction assessment?
- Mechanical
  - Enough shielding? Does it all fit in the box? Vibration levels achievable? Under mass?
- Power
  - Long eclipses? Extra heaters required? Slow initial sun acquisition?
- Radiation
  - External components resistance to atomic oxidization? Surface charging?
  - Individual component total ionizing dose? Single event upset detection and correction?
- Thermal
  - Coatings for both long eclipses and extended sun periods?

Architecture

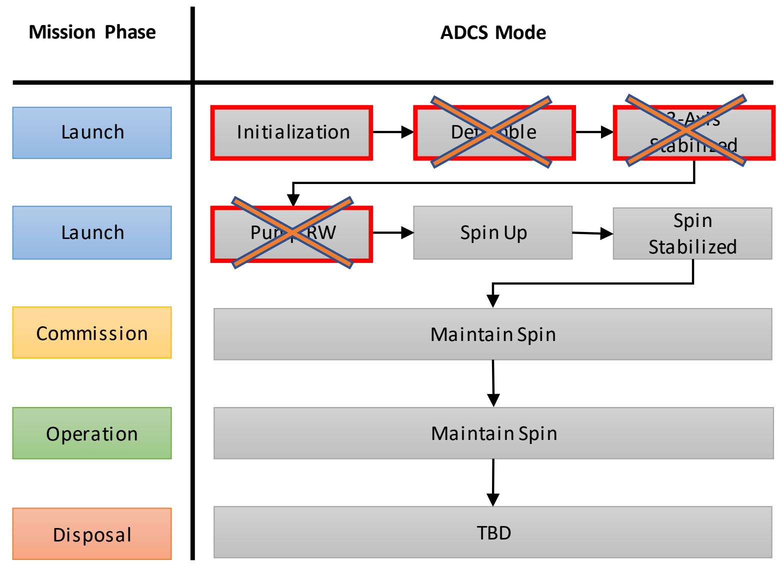
- Commercial
  - CubeSpace
    - Custom MTBs x 3
    - Medium RWs x 3
  - DHV Solar Arrays
  - Ibeos EPS
    - 45Whr Batteries x 4
  - SolarMEMS D60RH x 7
  - Vulcan Wireless Radio
- Custom
  - Backplane
  - C&DH
  - Chassis
  - Z-Shield





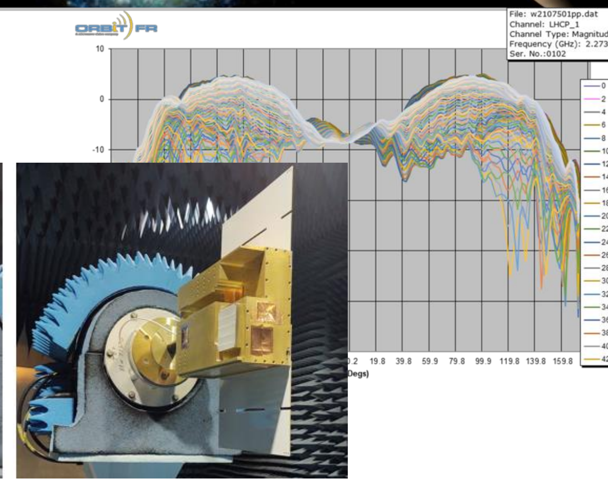
Attitude Determination and Control System

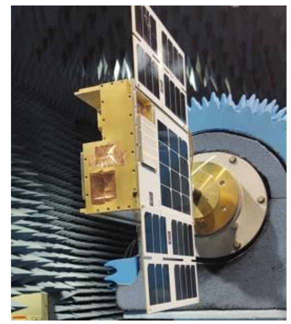
- Initial design required more authority
  - Acquired custom MTBs from CubeSpace
- Required to simplify design further to resolve issues
  - IMU expected to fail due to Helium exposure
  - RWs failed during flight proof vibration test
- Final design
  - Utilize tip-off momentum by transitioning it into our spin axis
  - Special cases and lots of tuning to resolve issues found during Monte Carlo runs in 42

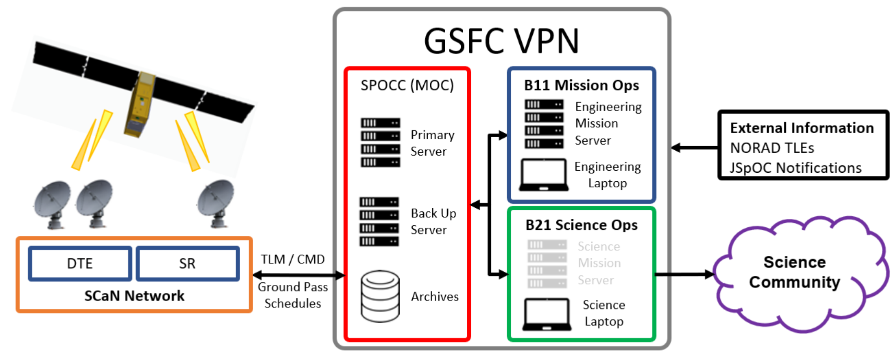


Communications

- Vulcan Radio and Antennas
  - Splitter to antennas on top and bottom
- Direct To Earth
  - Full Duplex
  - 50 kbps uplink / 500 kbps downlink
    - Reduced downlink from maximum due to C&DH throughput and link issues
- Space Relay Demand Access Service
  - 2kbps downlink only
  - TDRS-ANY mode
    - Accepts “unplanned” transmits from spacecraft
- Testing
  - Antenna pattern testing at NASA WFF
  - End-to-end compatibility testing at GSFC

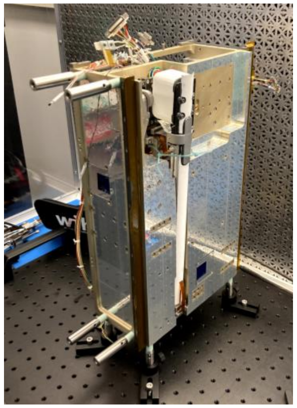


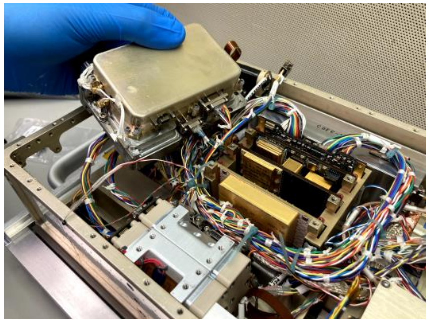


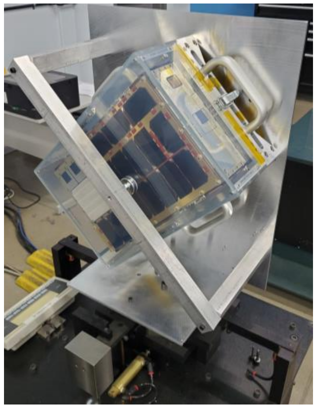


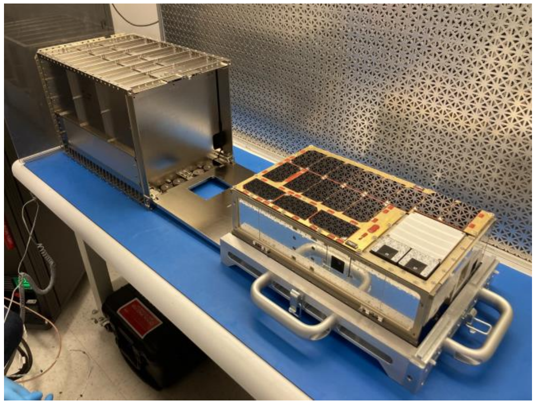
Mechanical Structures and Mechanisms

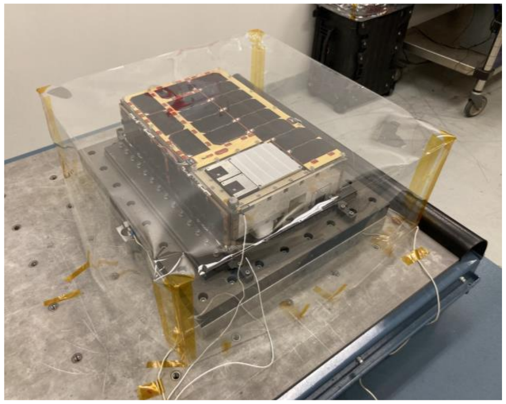
- Structure
  - 0.15" vault aluminum chassis
    - Lowers TID to acceptable levels
  - Custom one meter boom
  - PSC CSD deployer
  - Z-Shield lid and GSE cover
    - Provided by NASA Langley
- Integration and transport
  - Optical posts thread into chassis
  - Custom carrying case
- Testing
  - 3D printed model
  - Mass properties
  - Fit check into deployer
  - Flight proof vibration (+3db over)





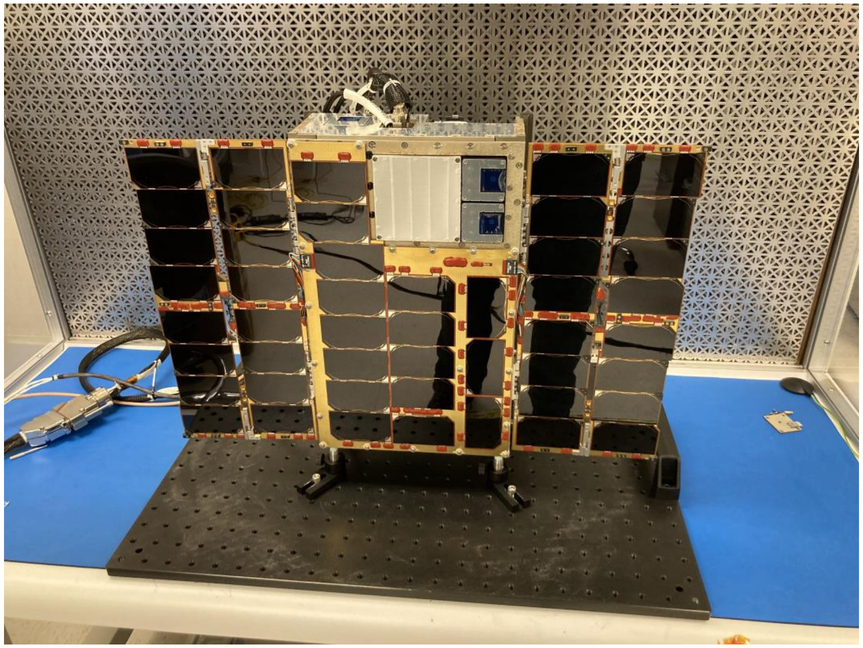






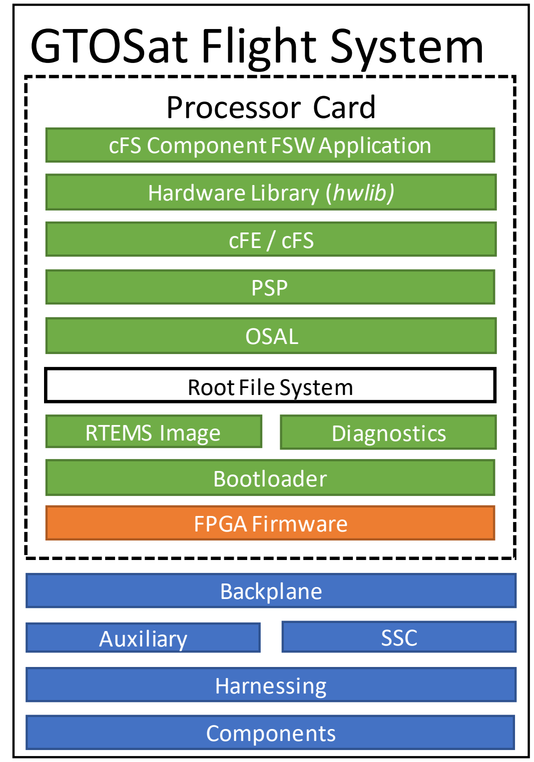
Power System

- DHV Solar Arrays
  - Custom sizing with back-wiring
    - Limits magnetic interference with bus
  - Double deployable wings
  - Specialty coatings
  - Standard burn wire circuitry
- Ibeos Electrical Power System
  - 45Whr Batteries x 4
  - I2C communications
  - Components isolated to individual switches when possible
  - Standard dual fault tolerant scheme for inhibits not including a remove before flight



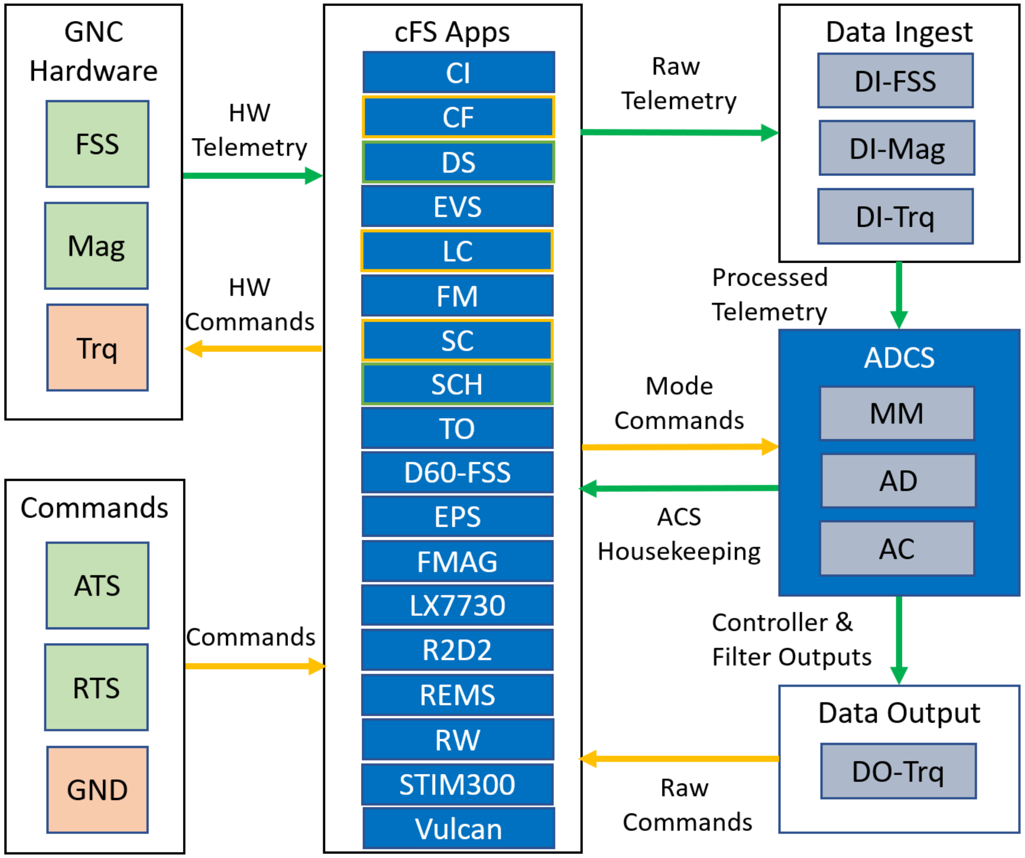
Command and Data Handling

- MARES
  - Modular Architecture for a Resilient Extensible SmallSat
  - TID > 30krad and SEL immune
  - Processor card
    - RTG4 FPGA with LEON3FT softcore
    - 16GB nonvolatile flash memory
  - Auxiliary card
    - Protocol support, LX7730 ADC, and science dosimeter
- Special Services card
  - Rad-Tol DC/DC converter for -12V to FMAG
  - H-Bridge and deployment circuitry
- Software
  - Real-Time Executive for Multiprocessor Systems (RTEMS)
  - core Flight System (cFS)
  - NASA Operational Simulator for Small Satellites (NOS3)

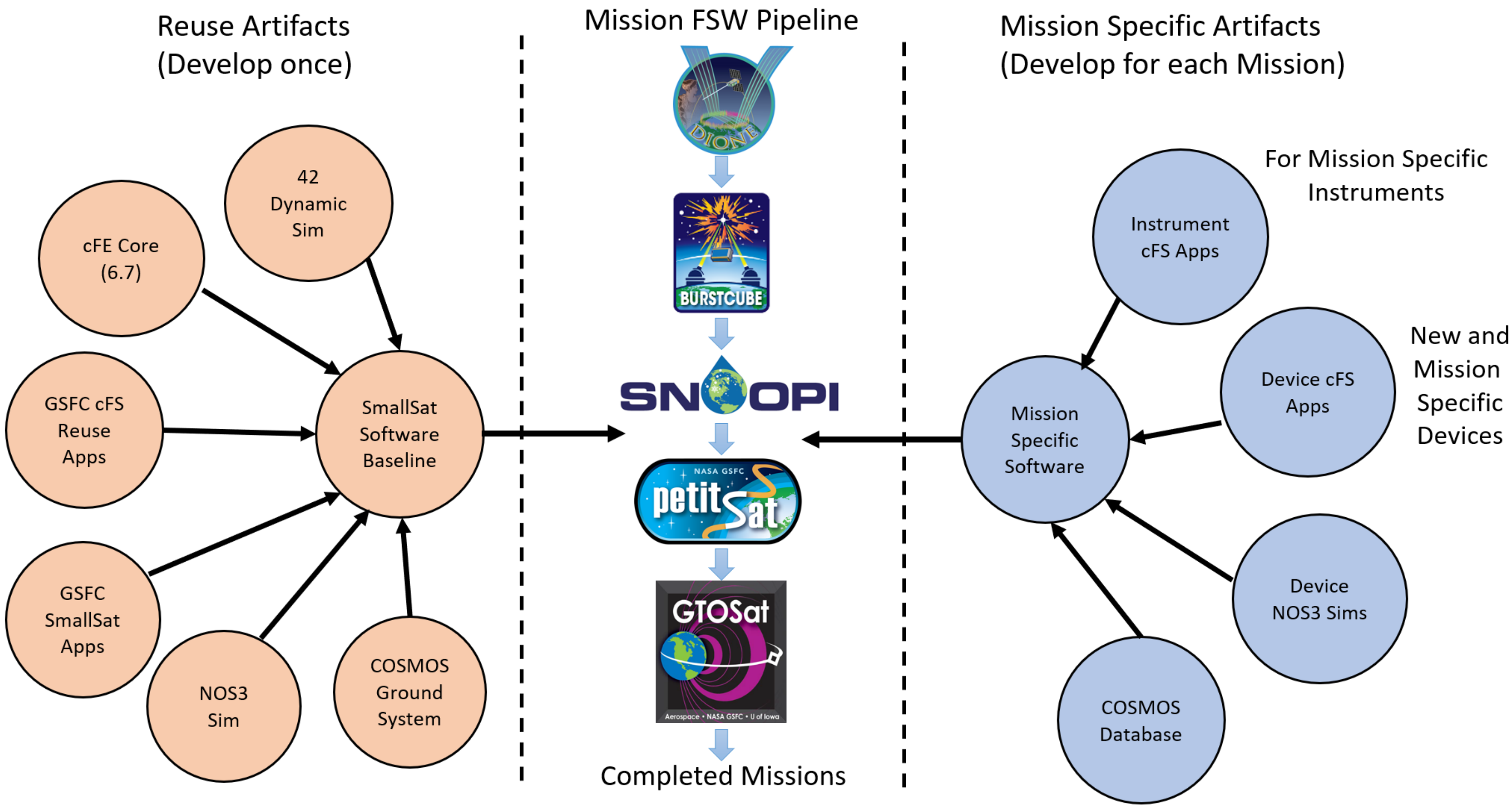


Flight Software

- Scheduler (SCH)
  - Generates data via commands to applications to produce it
- Data Storage (DS)
  - Stores set amount of data
  - Filter specific packets into files
- CFDP (CF)
  - Transfer files to/from ground
- Stored Commands (SC)
  - Relative Time Sequence (RTS)
  - Mission specific
- Limit Checker (LC)
  - Monitors telemetry packets
  - Responds by running an RTS

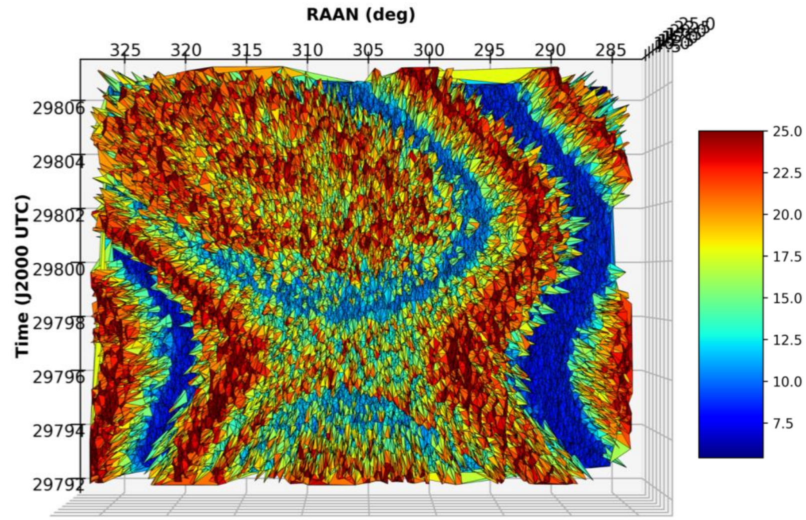


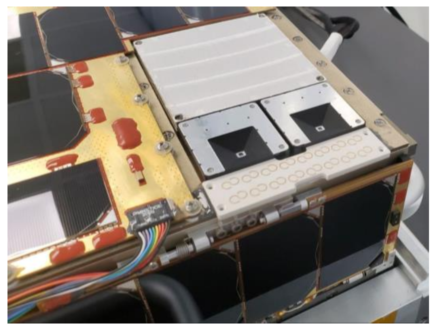
Multi-Mission Reuse Approach

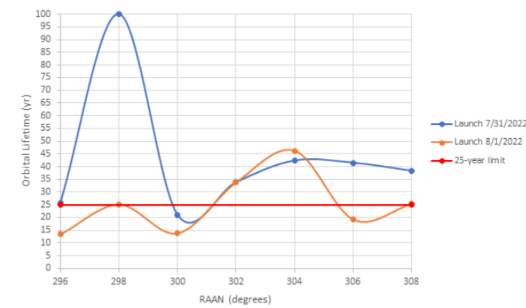


Launch - EZIO-6 / SBIRS GEO-6

- Deorbit Analysis
  - Final launch window had some of the longest lifetimes
  - Waiver required for 25-year rule
- Tracking
  - Van-Atta Retroreflector added
    - Compliments of SWARM and SPAWAR
    - SSC20-WKVI-04
  - Installed at delivery facility
- SBIRS GEO-6
  - Launched without secondary payloads







Path Forward

- Conjunction Assessment and Risk Analysis
  - Working directly to ensure compliance with requirements
  - GTOSat is the pathfinder
    - Helping to define how future missions obtain compliance
    - Whitepaper in work to document process and decisions made along the way
- Storage
  - De-integrating spacecraft from deployer
  - Returning to NASA GSFC for long term storage
- Working on a new launch opportunity
  - NASA CubeSat Launch Initiative (CSLI)
  - Space Force Mission Manifest Office (MMO)

Special thanks to everyone who made this possible

- Co-I, Lauren Blum
- Co-I, Larry Kepko
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- MSE, John P. Lucas
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- ADCS, Pavel Galchenko
- COMM, Behnam Azimi
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- Mechanical / I&T, Steven West
- Power / I&T, Dakotah Rusley
- Thermal, Michael Madden
- Scientist, Mykhaylo Shumko
- REMS
  - PI, Christine Gabrielse
  - PM, William Chavez
  - SE, William Crain
  - EE, Susan Crain
  - ME, Geoff Maul
  - Scientist, Drew Turner
  - Scientist, J. Bernard Blake
  - Scientist, James Clemmons
- FMAG
  - PI, Jared Espley
  - EE, David Sheppard
  - ME, Scott Murphy
  - Scientist, Jacob Gruesbeck

Too many others to mention!

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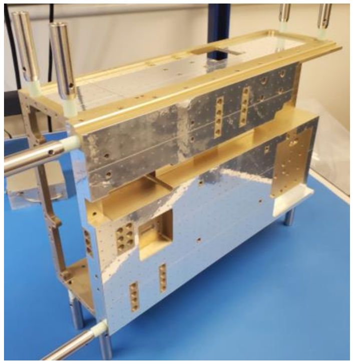
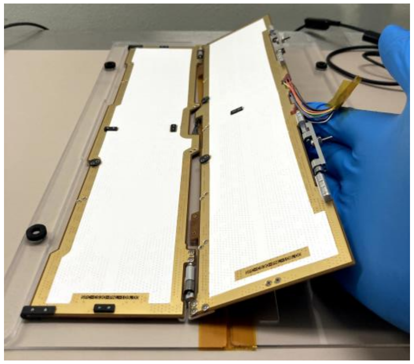
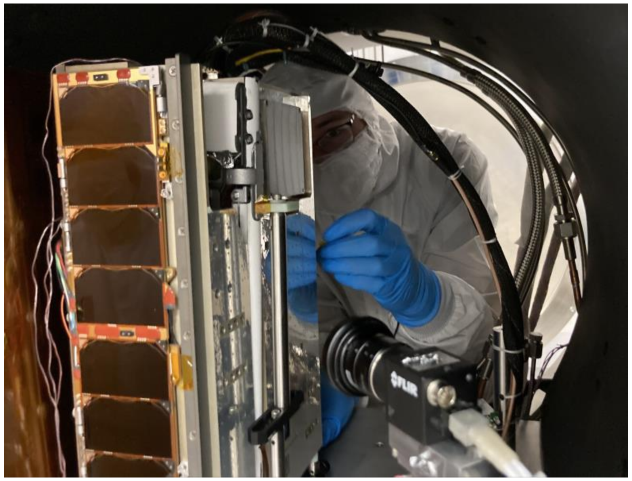
Thermal

- Cold biased passive design
  - Arrays and batteries isolated from bus
- Coatings
  - Ag FEP on bus
  - Z93C55 on back of arrays
- Minimal heaters
  - One on each battery pack – 9.6W
  - FMAG Sensor – 1W
  - REMS – 6W
  - Two spare bus heaters – 2W

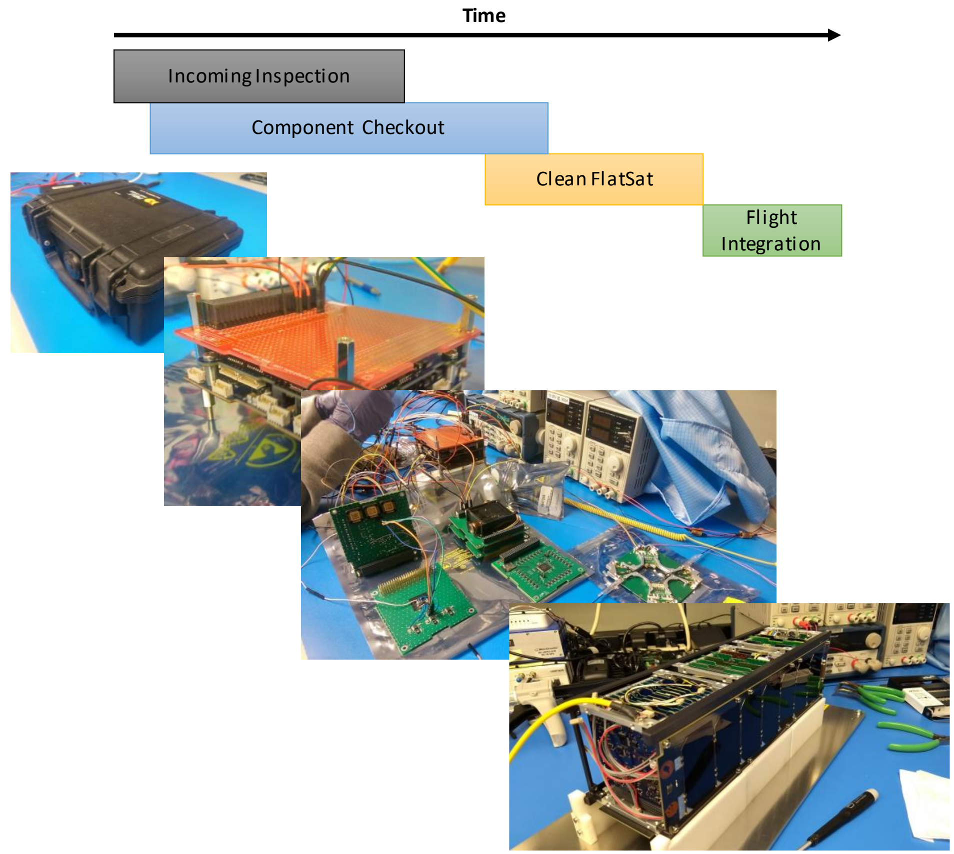






Workflow

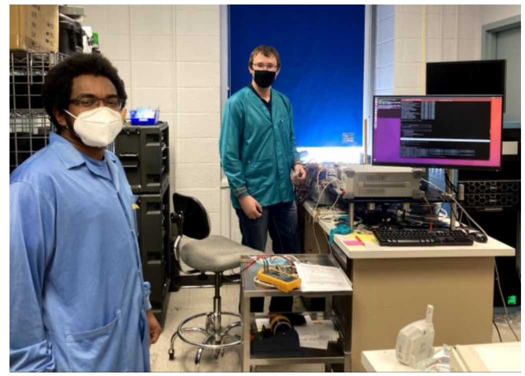
- Incoming Inspection
  - Utilize Work Order Authorizations (WOAs)
  - Visual part count and condition inspection
  - Photos of parts and storage location
- Component Checkout
  - Test configuration
  - Isolation / Resistance / Continuity (IRC)
  - Power measurements (in-rush and steady state)
  - Functional test
- Clean FlatSat
  - Use flight components and harness
  - Confirm ADCS component phasing
  - Inhibit and Thermistor Checkouts
  - Timing test
- Flight Integration
  - Fault detection and correction
  - Comprehensive Performance Test (CPT)

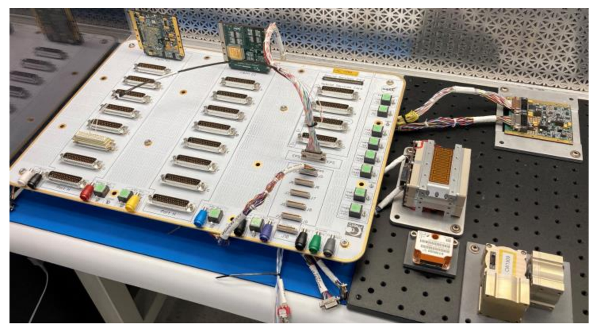


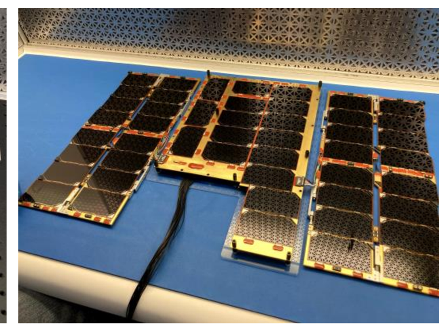
Issues Overcome – Component Checkouts

GTOSat

- Card Stack Issues Resolved
  - C&DH
    - ✓ LX7730 ADC reset logic updated
  - EPS
    - ✓ Low voltage protection logic updated
- Components Issues Resolved
  - Dual Antenna
    - ✓ Antenna pattern testing completed at WFF
  - Fine Sun Sensors
    - ✓ Issue with floating point unit resolved
  - Inertial Measurement Unit
    - ✓ Parsing algorithm reworked due to high data rate
  - Reaction Wheels
    - ✓ Enable lines for X and Y tied together

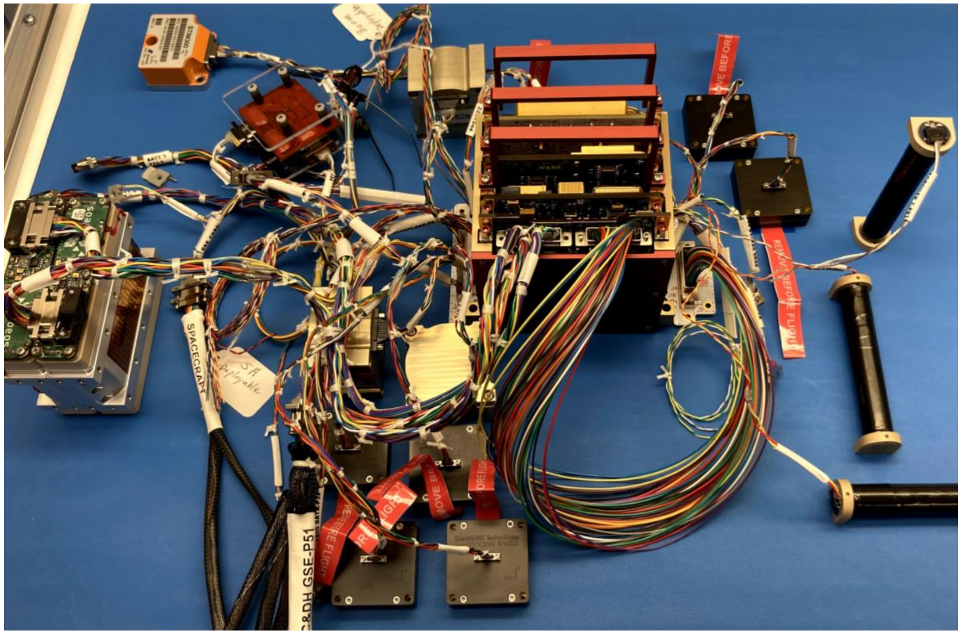






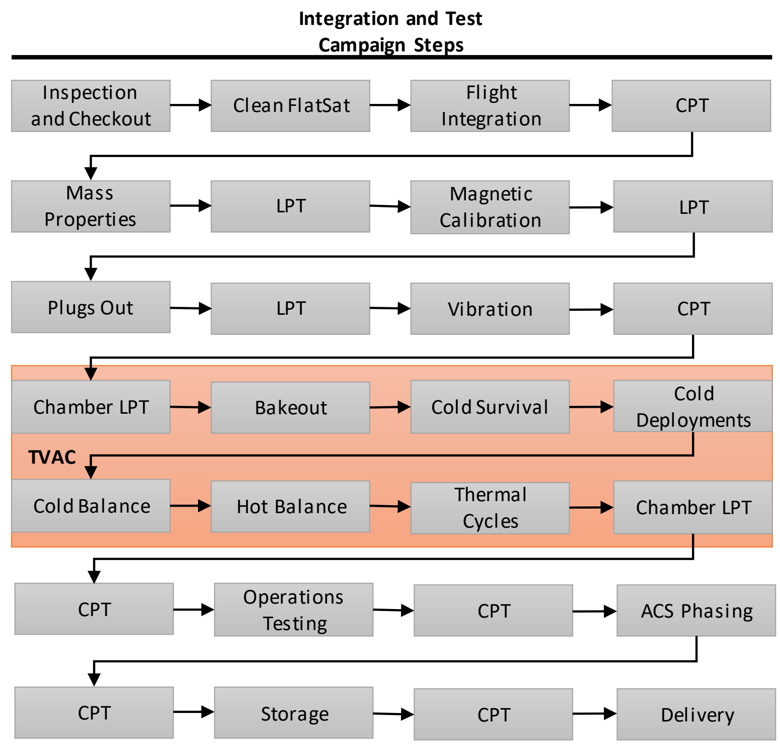
Issues Overcome – Clean FlatSat

- Card Stack Issues Resolved
  - ✓C&DH JTAG harness
  - ✓Inhibit harness improvement
- Component Issues Resolved
  - FMAG Emulator
    - ✓ Issue with data processing resolved
  - Radio
    - ✓ Baud rate out of supported range
  - REMS Emulator
    - ✓ Added JTAG interface for future updates
  - Solar Arrays
    - ✓ Issue with single cell resolved



Integration and Test Campaign

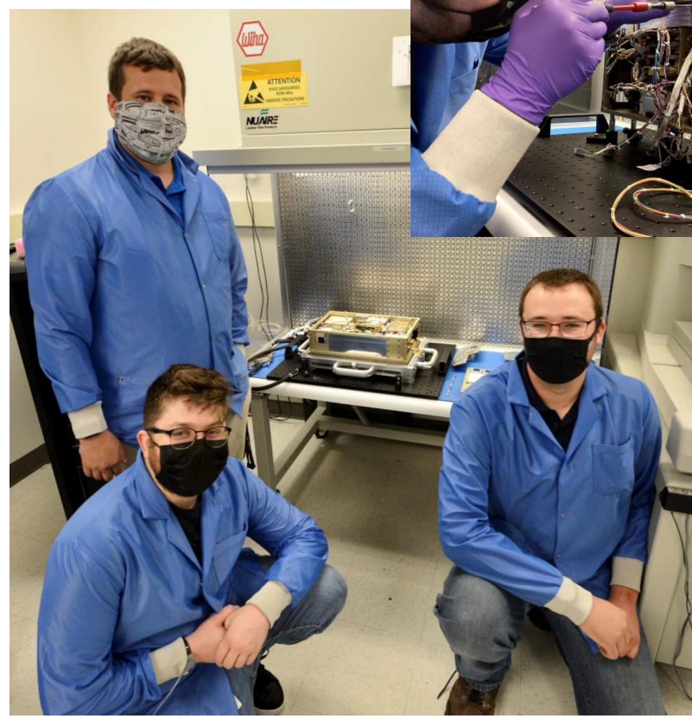
- Comprehensive Performance Test
  - Verify spacecraft functionality
  - External sensors and different spacecraft configurations / orientations
- Limited Performance Test
  - Fully automated
  - No external sensors or measurements
  - Aliveness, commanding, and system

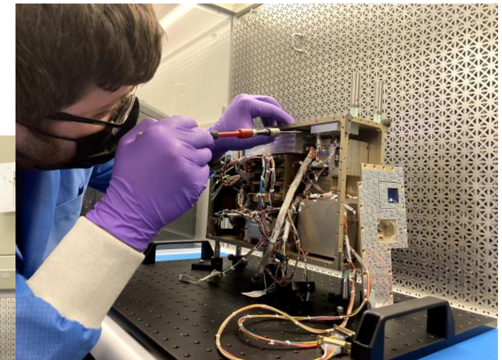


Issues Overcome – Integration and Test Campaign

GTOSat

- Integration issues resolved
  - ✓ C&DH
    - ✓ Processor utilization
    - ✓ Radio throughput
  - ✓ FMAG
    - ✓ Harness interference
- Test issues resolved
  - ✓ Fit Check
    - ✓ Inhibit switches proven to work (again)
  - ✓ Radio
    - ✓ Near Space Network campaign reduction
    - ✓ Spacecraft end-to-end RF testing
  - ✓ Vibration
    - ✓ "Max Random" button required for test





Lessons Implemented on GTOSat

- Buddy system implemented for hardware and procedures
- Debug RF port in addition to multiple consoles available in umbilical
- Integration and handling considered early
- Testing
  - Test as you fly
  - Keep it simple
  - Prioritize system level
  - Test soon and often
- Workflow defined and followed for all components

Lessons Learned

- Confirm throughput and system overhead incurred in each component
- Encourage experimentation
  - Procedures required prior to running on flight hardware
- GEVS may not truly be all encompassing
  - "Flight proof" vibe levels
- If it can be updated, ensure you can do it after integration
- Keep the team small and dedicated
- Perform deployment testing prior to TVAC
  - Obtain an engineering model to allow procedures and technique to be extensively tested
- Schedule time to:
  - Capture lessons learned
  - Maintain a realistic schedule
  - Update risks and issues

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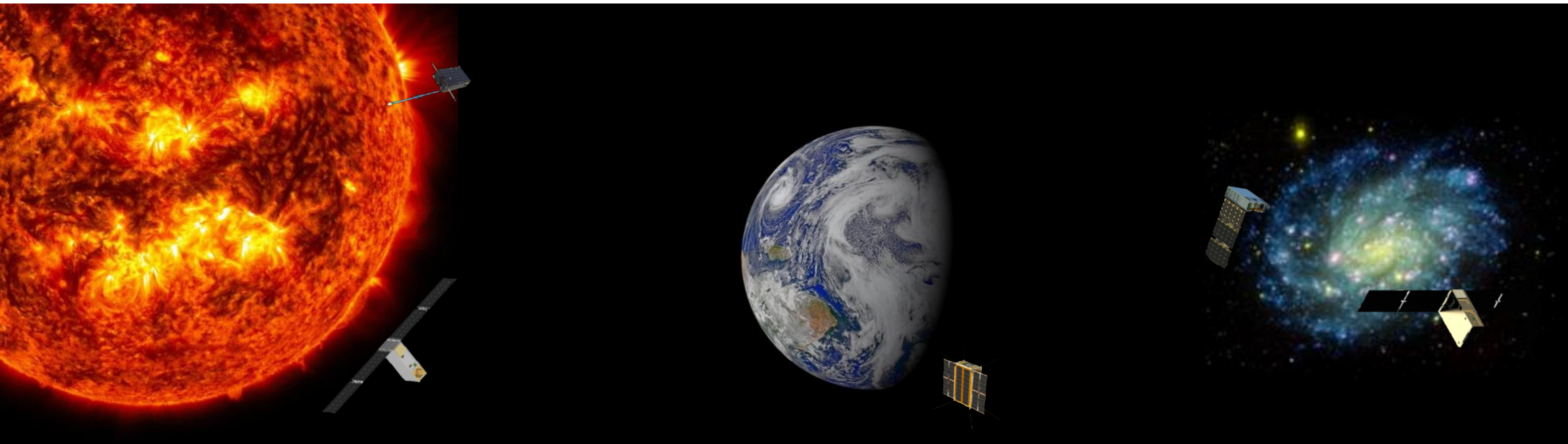

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