# FlexBus – A 6U Cubesat Platform for Any Mission

**Dan Hegel**
**GN&C Lead**
***Blue Canyon Technologies***

**hegel@bluecanyontech.com**

# Agenda

- Profile, Personnel & Products
- Programs in Production
- Payload Packaging & interfaces
- Power generation
- Pointing Performance & orbit Propagation
- Programming (i.e. software)
- Propulsion
- Particles (i.e. radiation)
- Propagation of command & telemetry (i.e. comm)
- Planning and tasking (i.e. operations)

# Profile & Personnel

- BCT was founded in 2008 by industry veterans
- Staff of highly experienced engineering, production, procurement, and support personnel
  (Over 30 spacecraft prior to BCT)
- Located in Boulder, CO
- 23,000 square feet for manufacturing, test, and mission operations center
- Recent equipment & systems automation investments
- Facility enhancements for volume manufacturing & test

# Products

**Nano Star Trackers**
High-performance, ultra-small size & power

**Reaction Wheels**
Nanosat, CubeSat, and Microsat sized wheels

**Attitude Control Systems**
Precision GN&C Systems for CubeSats and Microsats (enclosed or distributed architecture)

**Electrical Power Systems**
Batteries, solar panels, power control and distribution

**XB1 – Spacecraft Avionics**
Integrated Nanosat system (ADCS, EPS, C&DH, GPS), X-Band Transmitter

**XB1 Spacecraft Bus**
Complete Nanosat Spacecraft Bus Solution (Integration and Test, Launch, Operations)

# XB1 Avionics

## XACT-Based 1U Integrated CubeSat System

- Highest-available pointing performance from *Dual* Micro-Star Trackers
- Bus functionality for GN&C, EPS, Thermal, C&DH, SSR, option for RF Comm
- Interfaces and control provided for Payload, Propulsion, and Solar Arrays
- Supports configurations up to 27U
- Side by Side or Stacked Configurations available

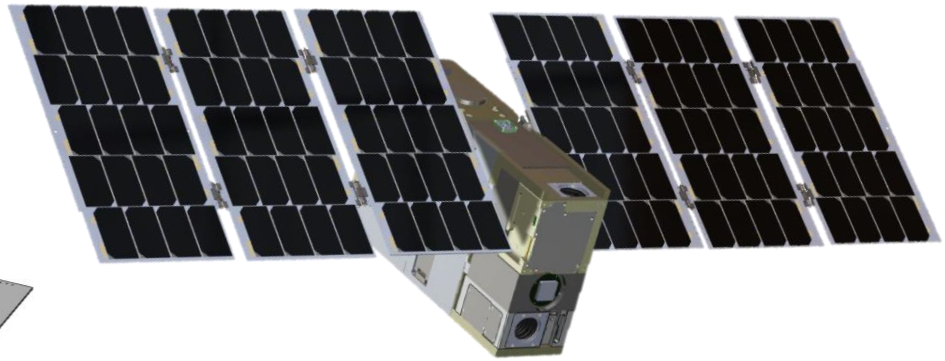
| | XB1 Parameter | Value/Notes |
|---|---|---|
| GN&C | Pointing Accuracy | ±0.002° (1-sigma), 3 axes, 2 Trackers |
| | Pointing Stability | 1 arc-sec/sec |
| | Maneuver rate | 10 deg/sec (typical 3U CubeSat) |
| | Orbit knowledge | 4m, 0.05m/s |
| CDH | Data Interfaces | Serial: LVDS, I2C, or SPI available |
| | Onboard Data Processing | Configurable via user loadable software |
| | Telemetry Acquisition | 6 12bit Analog, 6 discrete inputs |
| | Commands | Real-time, stored, macro |
| | Onboard Data Storage | 32 Gbytes |
| EPS | System Bus Voltage | 10 – 20 V (battery and array dependent) |
| | Energy Storage | Standard: 25Whr, expandable |
| | Solar Panels | Customer or BCT Provided Solar Panels (Details available per request) |
| | High Current Capability | Unregulated up to 60W |
| | Payload Power Feeds | QTY 6 (12, 5, 3.3V or Bus voltage) |

# Turn-key Spacecraft Solutions

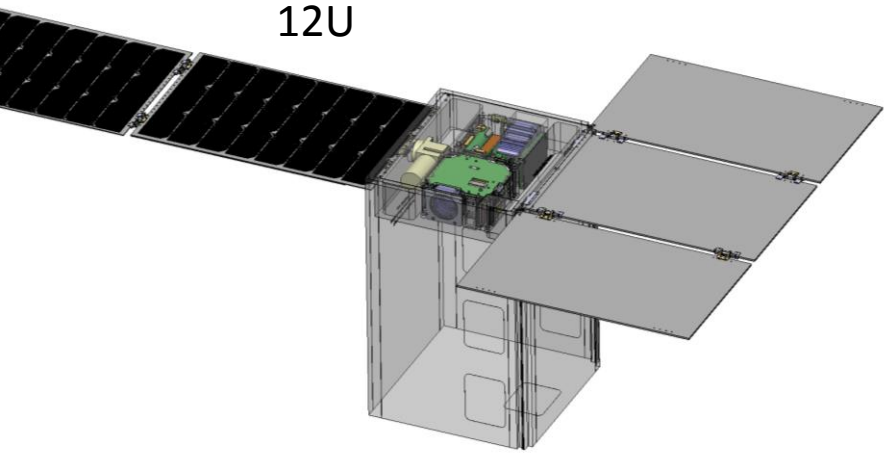
- XB1-based Spacecraft Buses
  - 3U, 6U, 12U
  - Support LEO, GEO, and deep-space
- Integration & Test
- Launch Vehicle Integration
- Mission Operations

3U

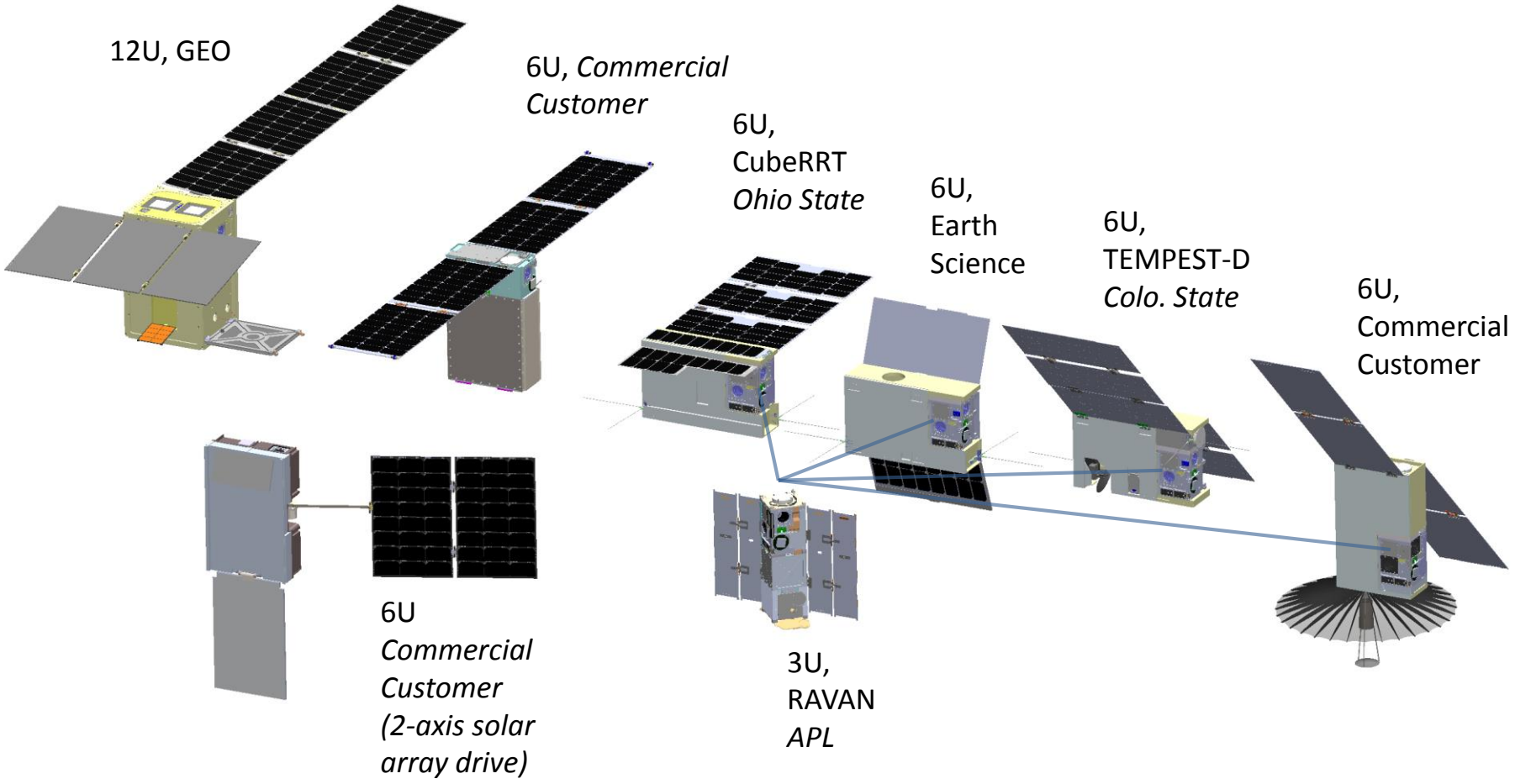
6U



12U

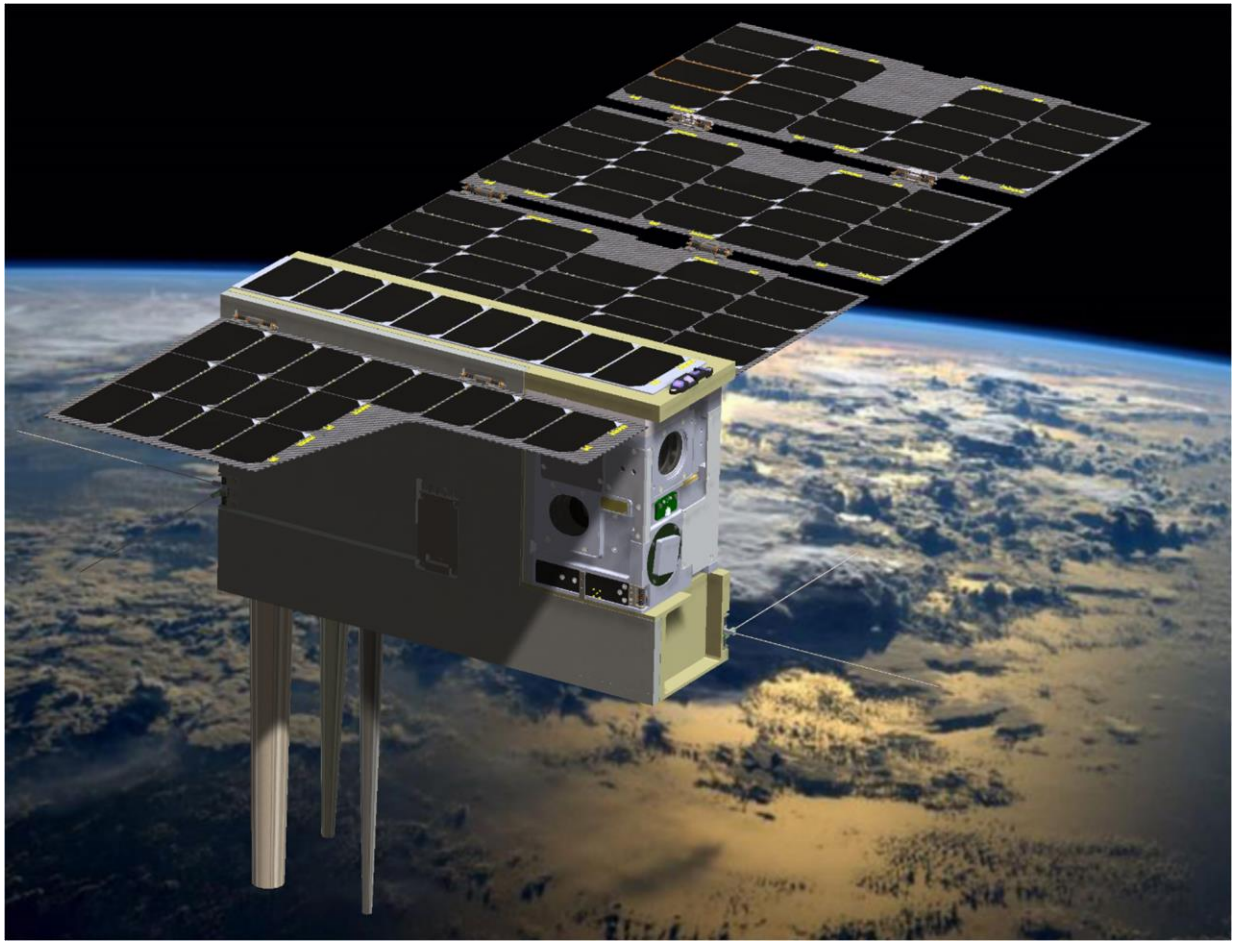


# Programs in Production



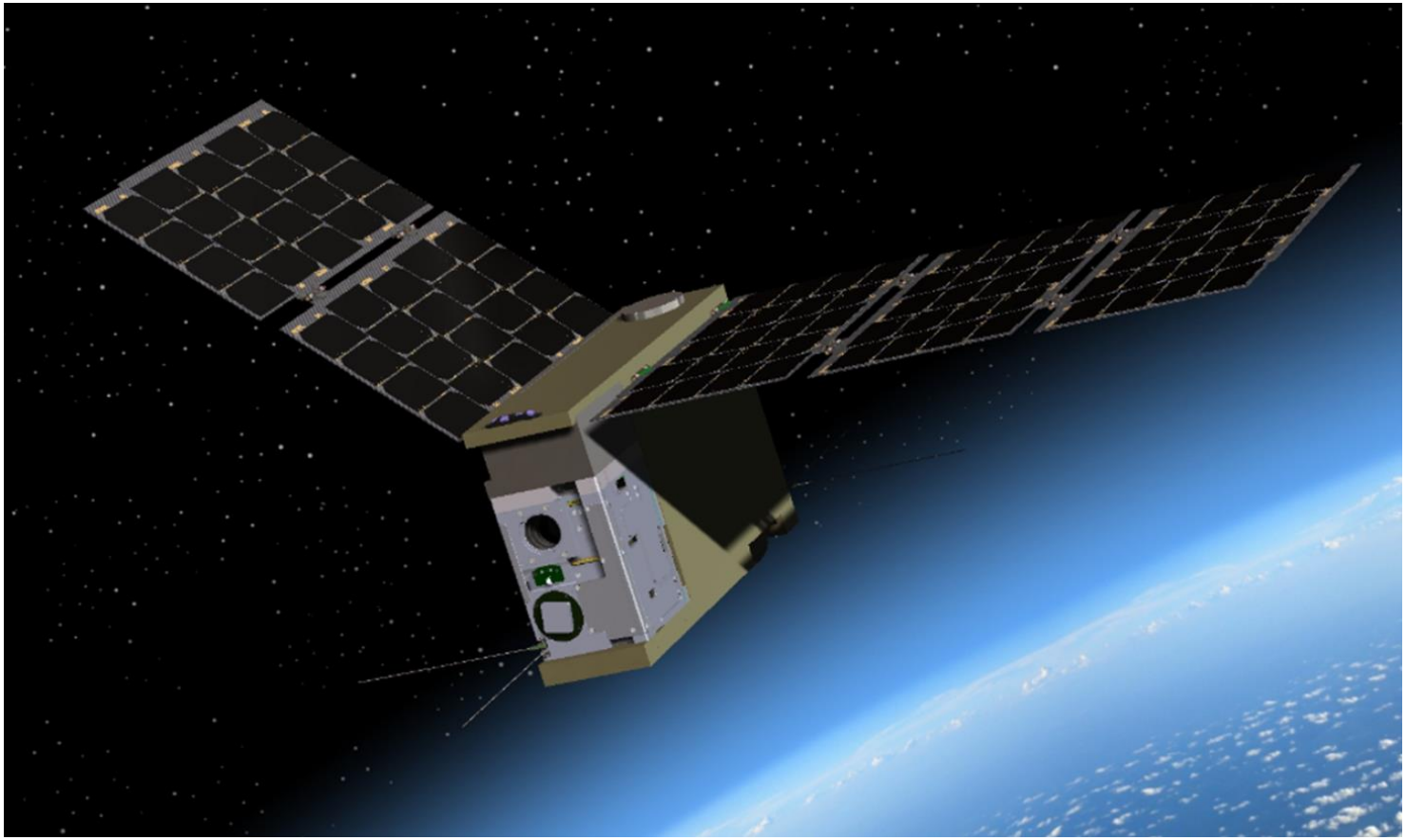
# CubeRRT

- The Ohio State University
- Interference mitigation for microwave radiometer



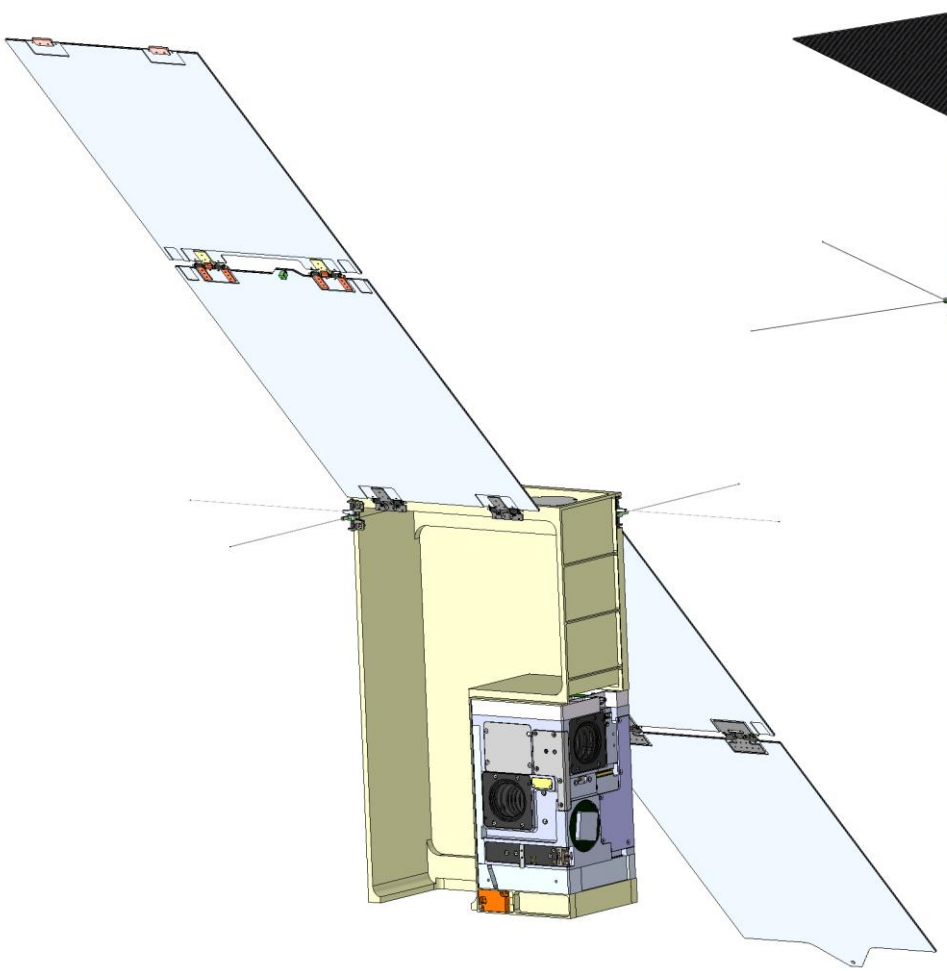
# TEMPEST-D

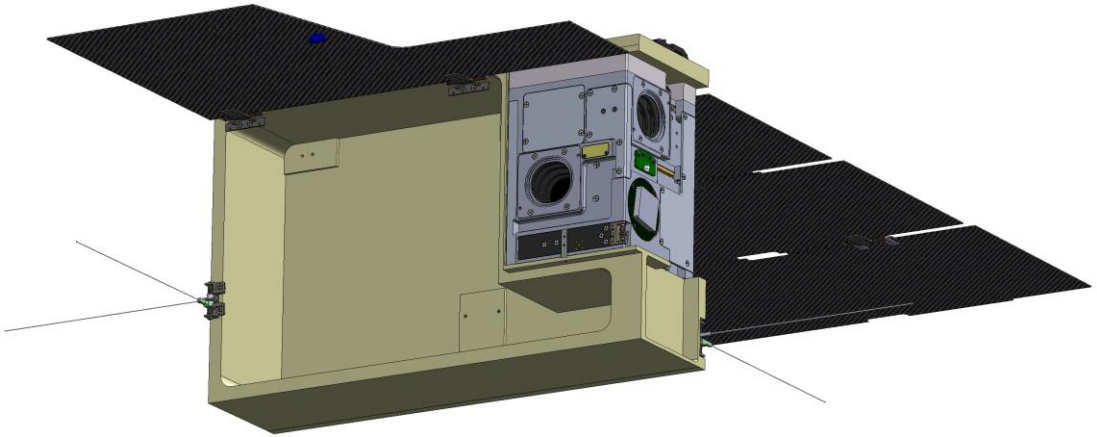
- Colorado State University
- Precipitation monitoring radiometer

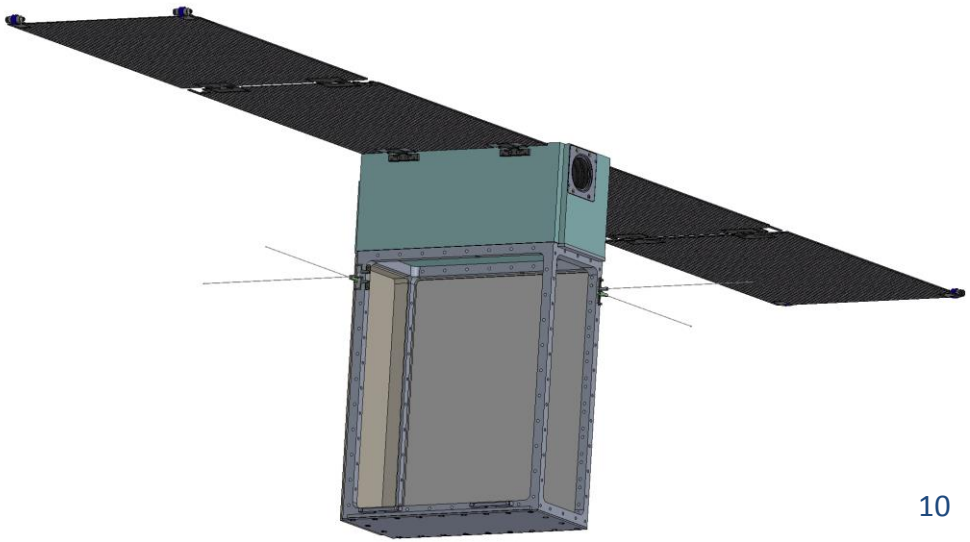


# Three, 6U Configurations Provide Payload Flexibility

- Support both CSD and NLAS dispensers







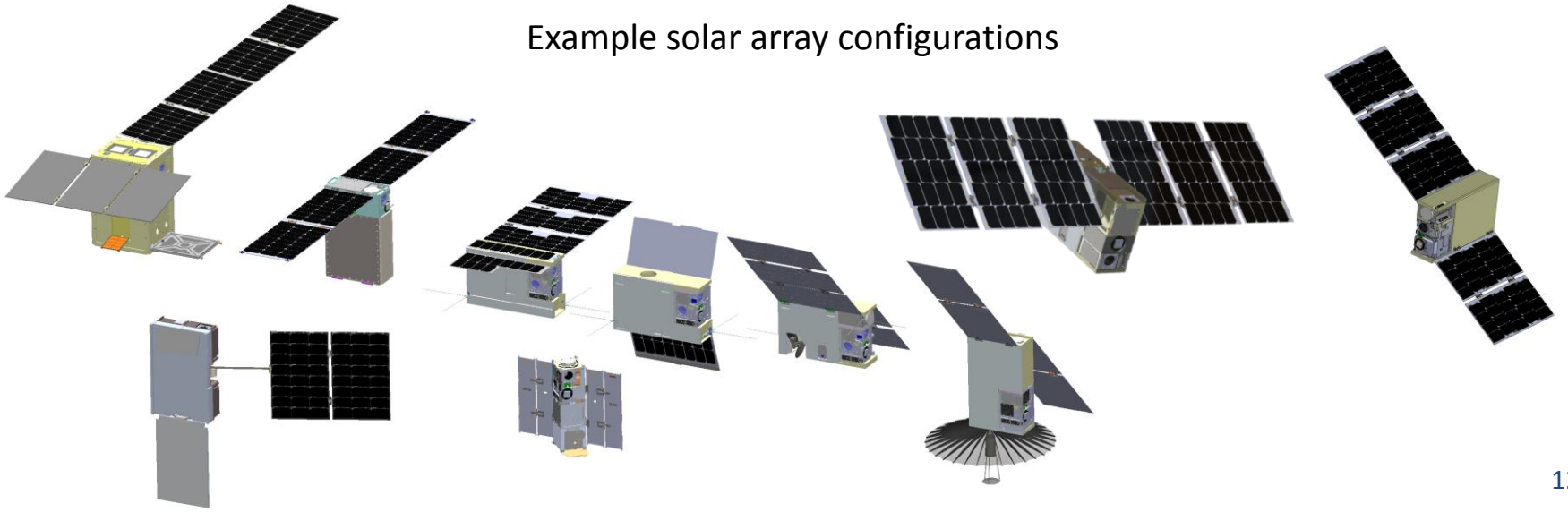
# Payload interfaces

- Payload is allocated one of two available ARM cores for any necessary data processing
- Combination of various physical layer options and FPGA allows XB1 to be compatible with many different serial protocols:
  - UART
  - SPI (Serial Peripheral Interface)
  - HDLC (High-Level Data Link Control) over LVDS
  - Spacewire over LVDS
  - Generic three wire clock, data, gate serial digital interfaces
  - I2C (Inter-Integrated Circuit)
  - CCSDS Command and Telemetry
  - TDM Command and Telemetry

# Power Generation

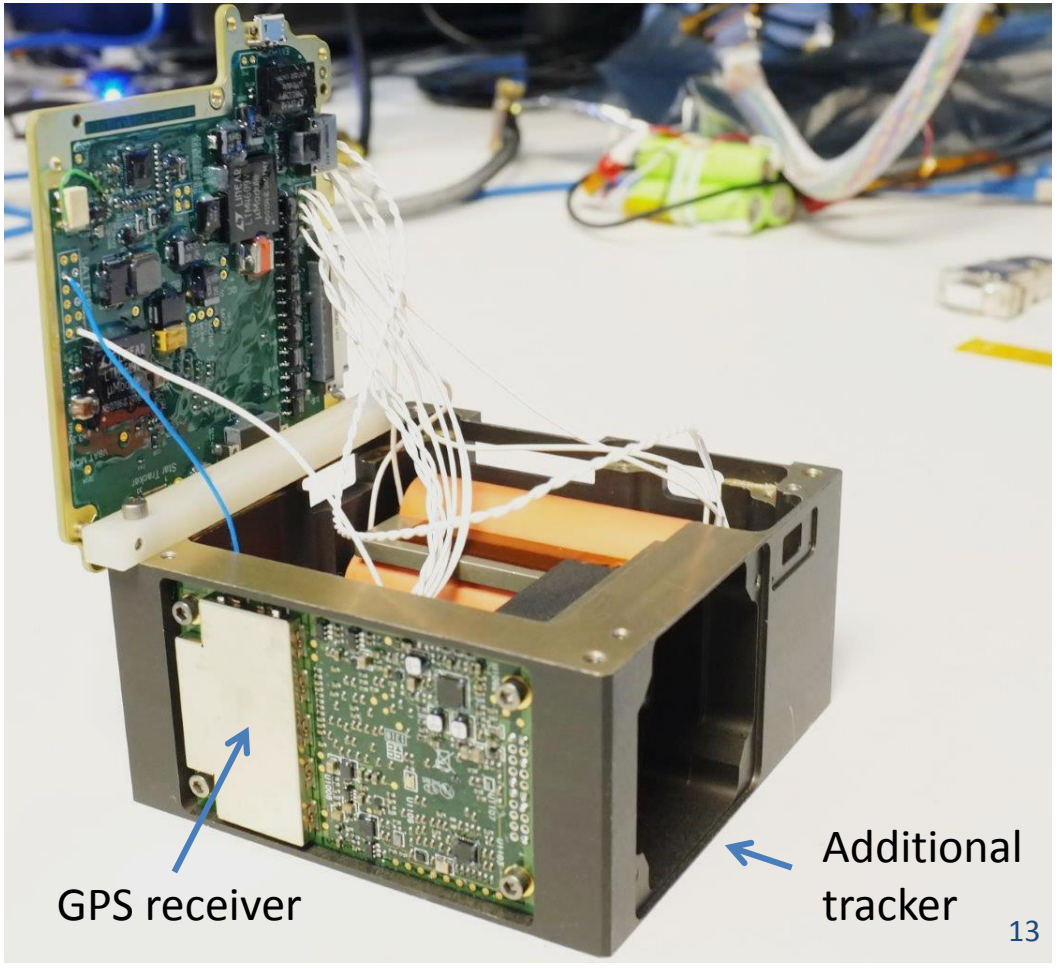
- Flexible solar panel configurations
- Variety of fixed deployment angles to maximize power across all Beta angles
- Micro-stepping drives available (Alpha and Beta drives)
- Can provide over 100W of power

Example solar array configurations



# XB1 Power Control Module

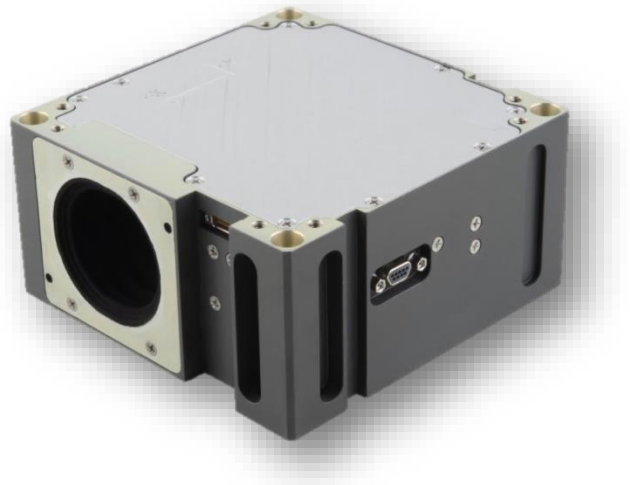
- Module compliments ADCS/C&DH module to provide complete avionics
- Includes battery, charge control board, GPS receiver, and redundant star tracker.
- Two orthogonal trackers provide superior pointing.
- Robust to sun intrusion.
- Charge control board supplies multiple switchable regulated voltages
- Batteries can be expanded up to 100 W-hr



# XB1 ADCS/C&DH Module

- XB1 ADCS/C&DH is similar to stand-alone XACT
  - Nano Star Tracker for precise attitude determination (Integrated stray light baffle)
  - Three micro sized (or larger) reaction wheels enabling precise 3-axis control
  - Three torque rods
  - MEMS IMU
  - MEMS Magnetometer
  - Sun sensors
- Multiple pointing reference frames, such as:
  - Inertial
  - LVLH
  - Earth-fixed target
  - Solar
  - Lunar
- Comm and SD card interfaces
- Highly-integrated architecture with powerful processing core

*0.5U ADCS/C&DH module*



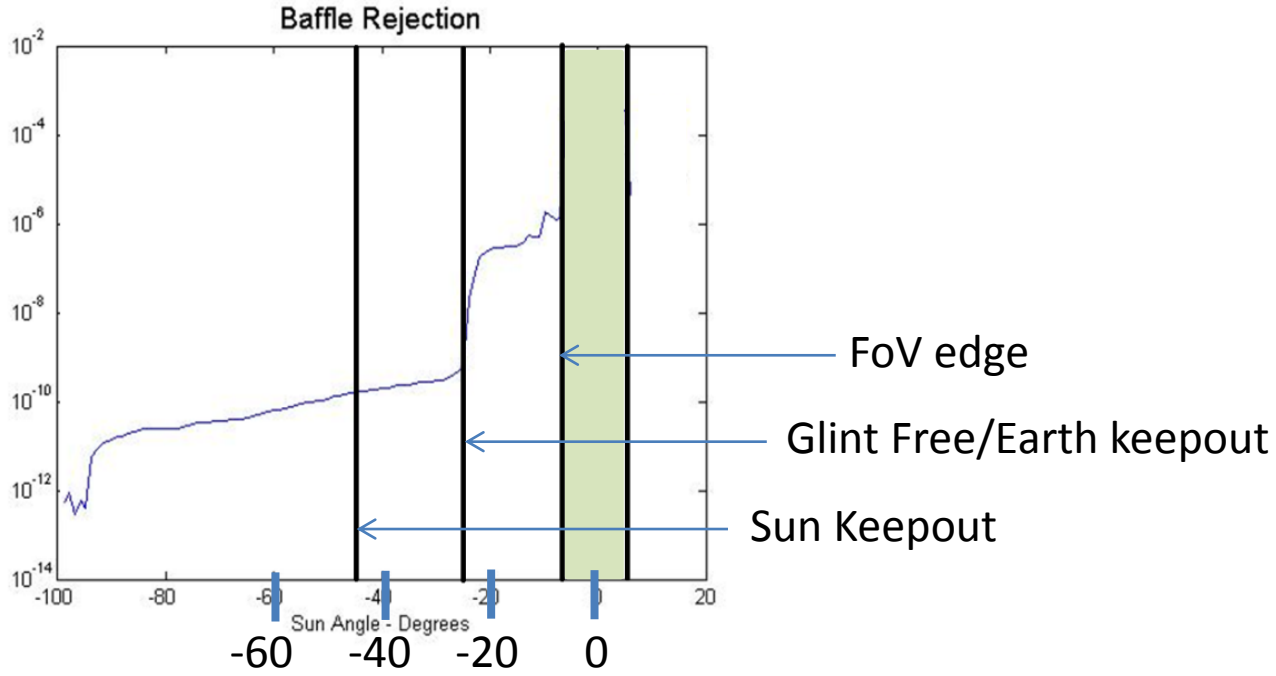
*Power module contains 2nd tracker.*

*Resulting pointing accuracy is 0.002 deg, RMS, at <1 deg/s*

# Stray Light Baffle Performance

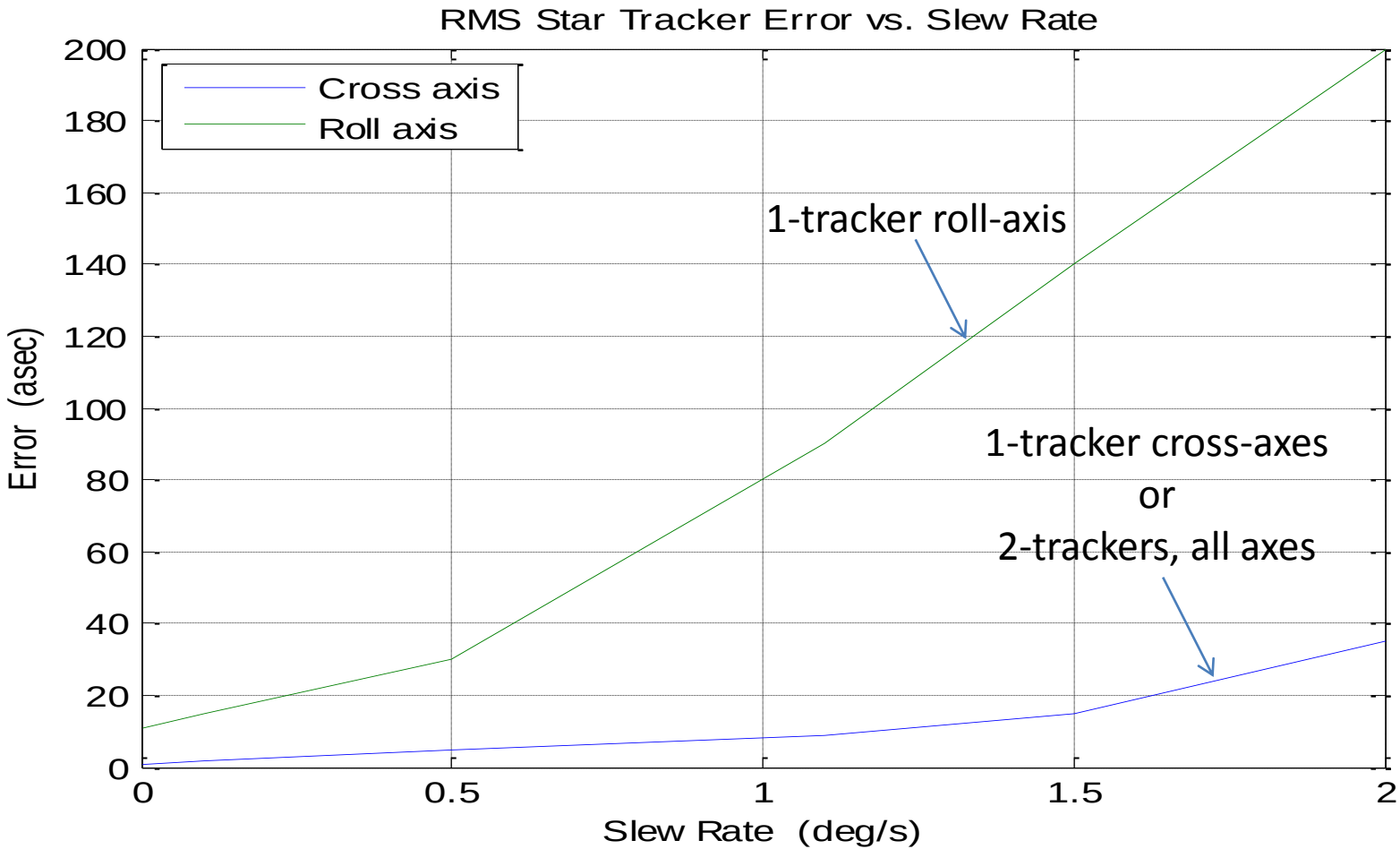
- Stray light baffle allows operation within <45 deg of sun, and 25 deg of earth.
- Performance was verified using a heliostat at CU LASP
- Results matched analytical model extremely well

Results of heliostat testing at CU LASP



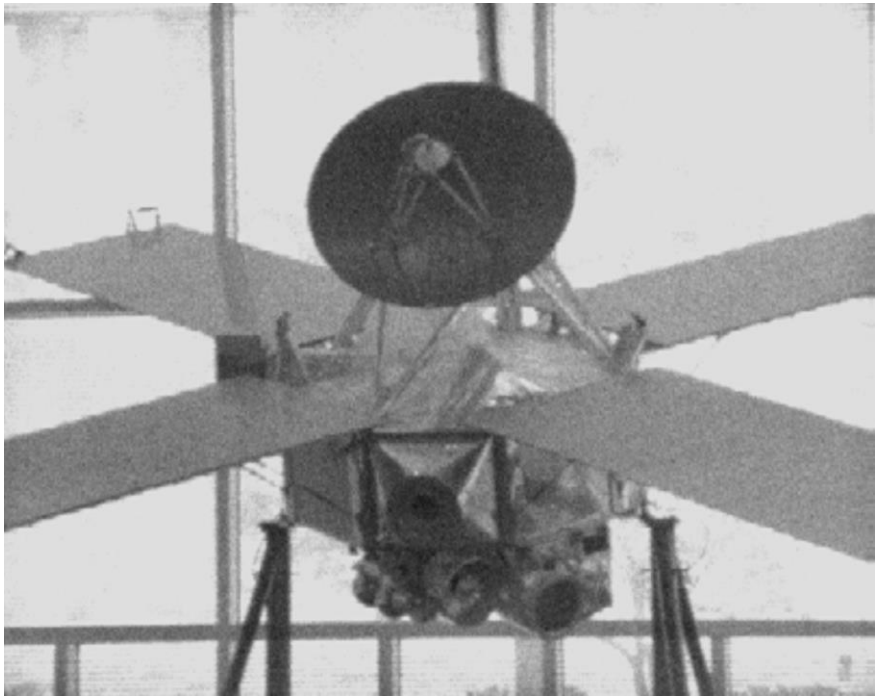
# Results of Night Sky Testing

- High-precision telescope gimbal used to slew NST at various rotation rates
- Mean motion removed, resulting in NST knowledge error



# Tracker Photo-mode

- User can command Photo mode using selectable gains and integration times.
- Can store and downlink full frame images

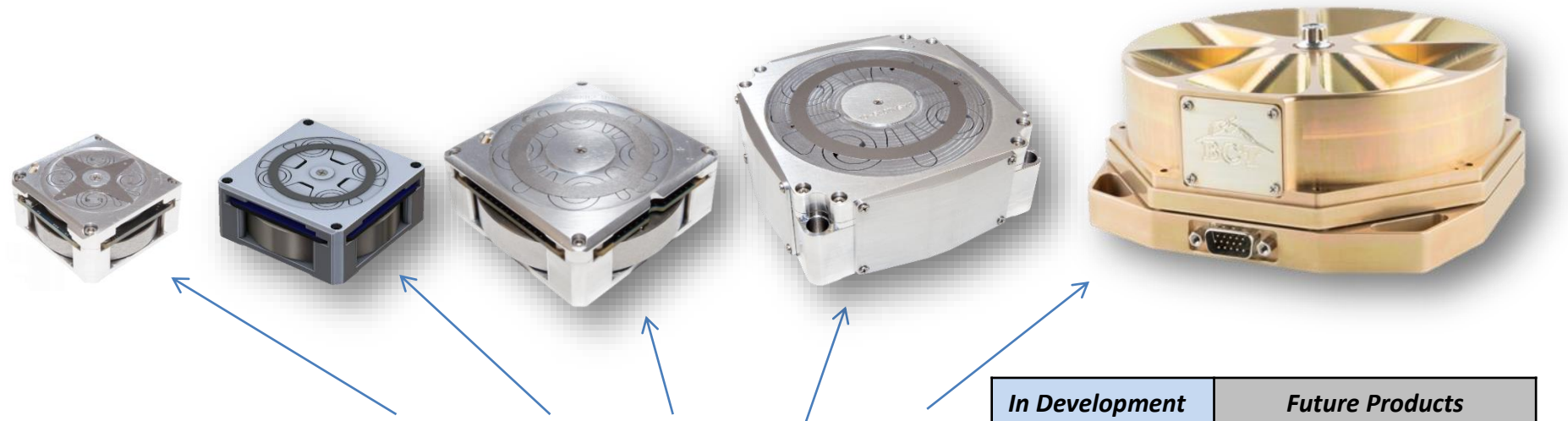


Spacecraft display in daylight.
(Lobby of CU LASP)
Short integration time.

“Star Wagon” at night.
Long integration time.

# Multiple Reaction Wheels Sizes Support Range of S/C Inertias

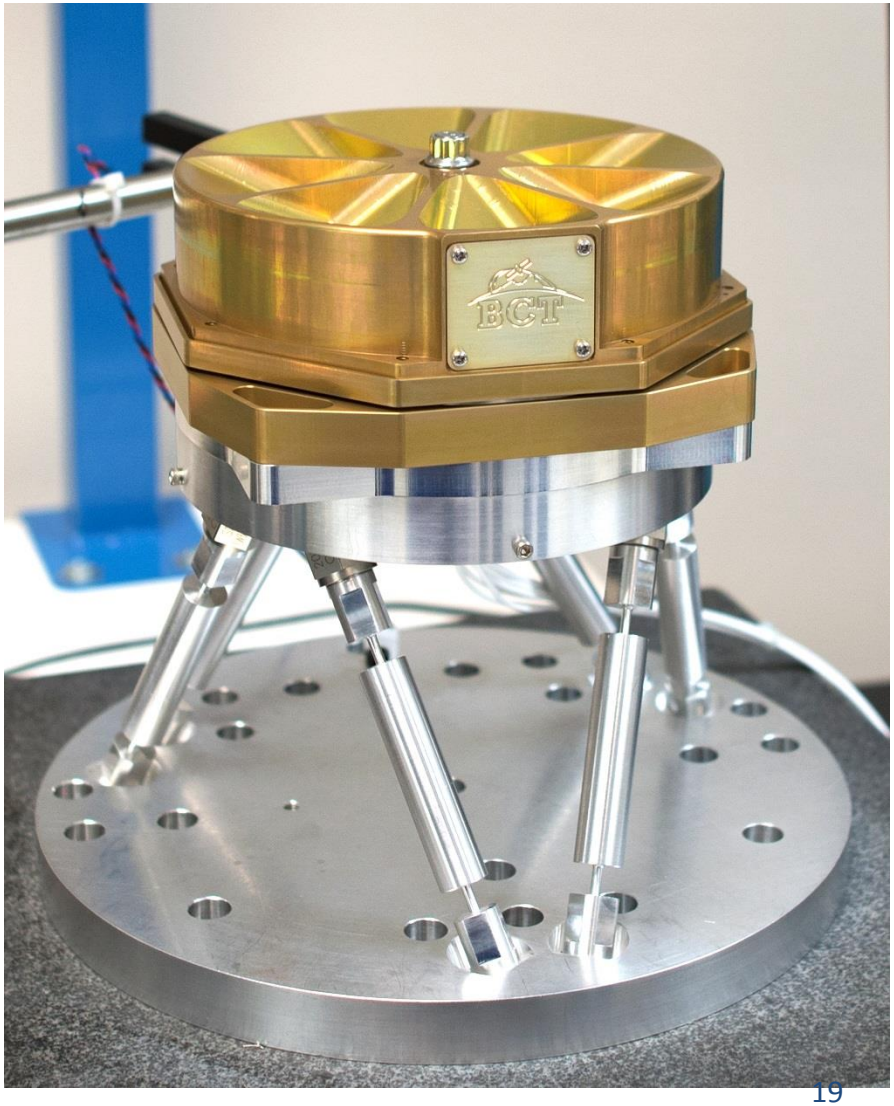
- If payload inertia is large, XB1 avionics can drive larger wheels to provide required agility



| | | | | | | | In Development | | Future Products | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Model # | RWp015 | RWp050 | RWp100 | RWp500 | RW1 | *RW4* | *RW8* | *RW12* | *RW25* | *RW50* |
| **Spec Torque** | ***Nm*** | 0.006 | 0.007 | 0.007 | 0.025 | 0.04 | 0.06 | 0.08 | 0.1 | 0.1 | 0.25 |
| **Max Momentum** | ***Nms*** | 0.015 | 0.050 | 0.100 | 0.500 | 1.5 | 4 | 8 | 12 | 25 | 50 |
| **Diameter** | ***cm*** | 4.3 | 5.8 | 7.0 | 11 | 15 | 16 | 17 | 19 | 21 | 25 |
| **Height** | ***cm*** | 1.8 | 2.3 | 2.5 | 3.8 | 7 | 9 | 9 | 11 | 11 | 12 |
| **RWA Total Mass** | ***kg*** | 0.115 | 0.24 | 0.35 | 0.85 | 1.5 | 3.1 | 3.3 | 4.9 | 6.9 | 9.3 |
| **Max Power** | ***Watts*** | 5.5 | 9 | 9 | 23 | 46 | 48 | 50 | 53 | 53 | 127 |
| **Nominal Power** | ***Watts*** | 0.5 | 0.5 | 0.5 | 3 | 5 | 5 | 5 | 7 | 7 | 9 |

# Wheel Disturbance Measurements

- Jitter Environment Measurement System (JEMS)
- Measures static and dynamic imbalance
- Produces waterfall plots of all disturbances

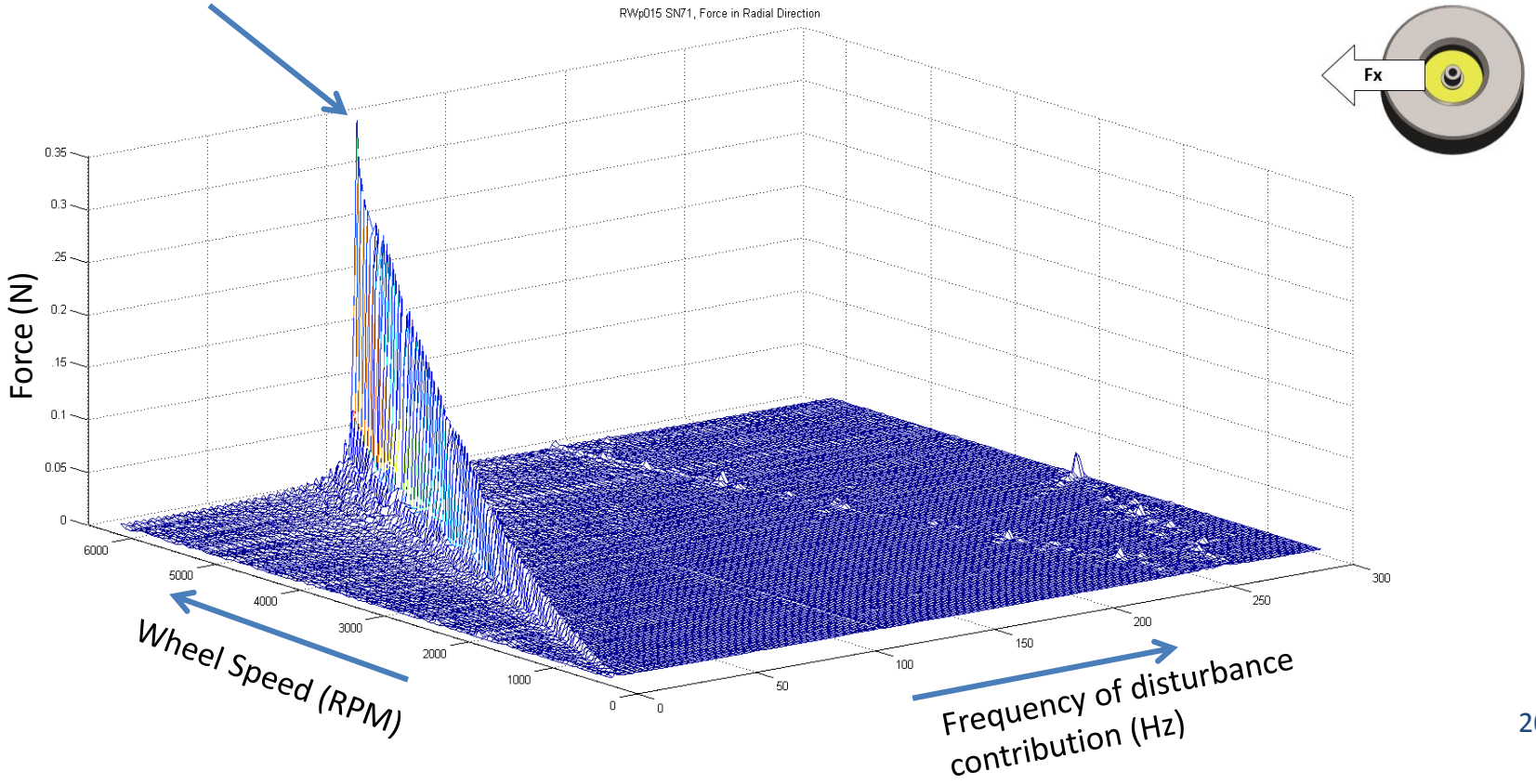


# Wheel Jitter Performance

- BCT wheels are designed for long life, and extremely low jitter
- Low wheel disturbances result in low payload line-of-sight motion
- Fine static imbalance < 0.3 g-mm for RWp015 wheels

*Low residual static imbalance force*

$F = mr\omega^2$

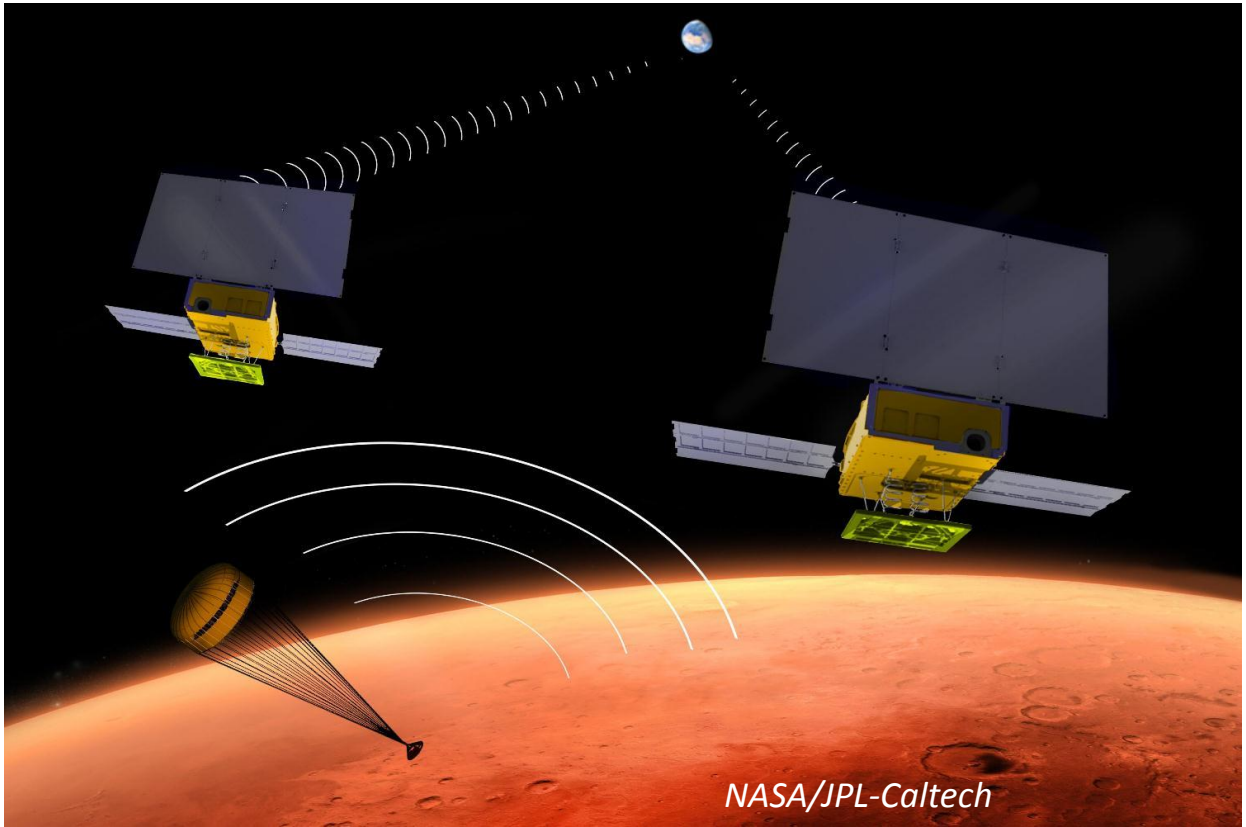


# Orbit Propagation

- XACT/XB1 utilize spherical harmonic or SGP4 orbit propagation for LEO
- BCT also implementing Kalman filter to support GPS-based orbit determination/propagation in geosynchronous orbit
- Algorithms were augmented to support JPL deep-space orbit propagation
- Supports orbit propagation around moon

BCT XACT implemented in JPL's MarCO Spacecraft.

XACT/XB1 deep-space orbit propagation is compatible with JPL orbit determination output.



*NASA/JPL-Caltech*

# Programming (i.e. software)

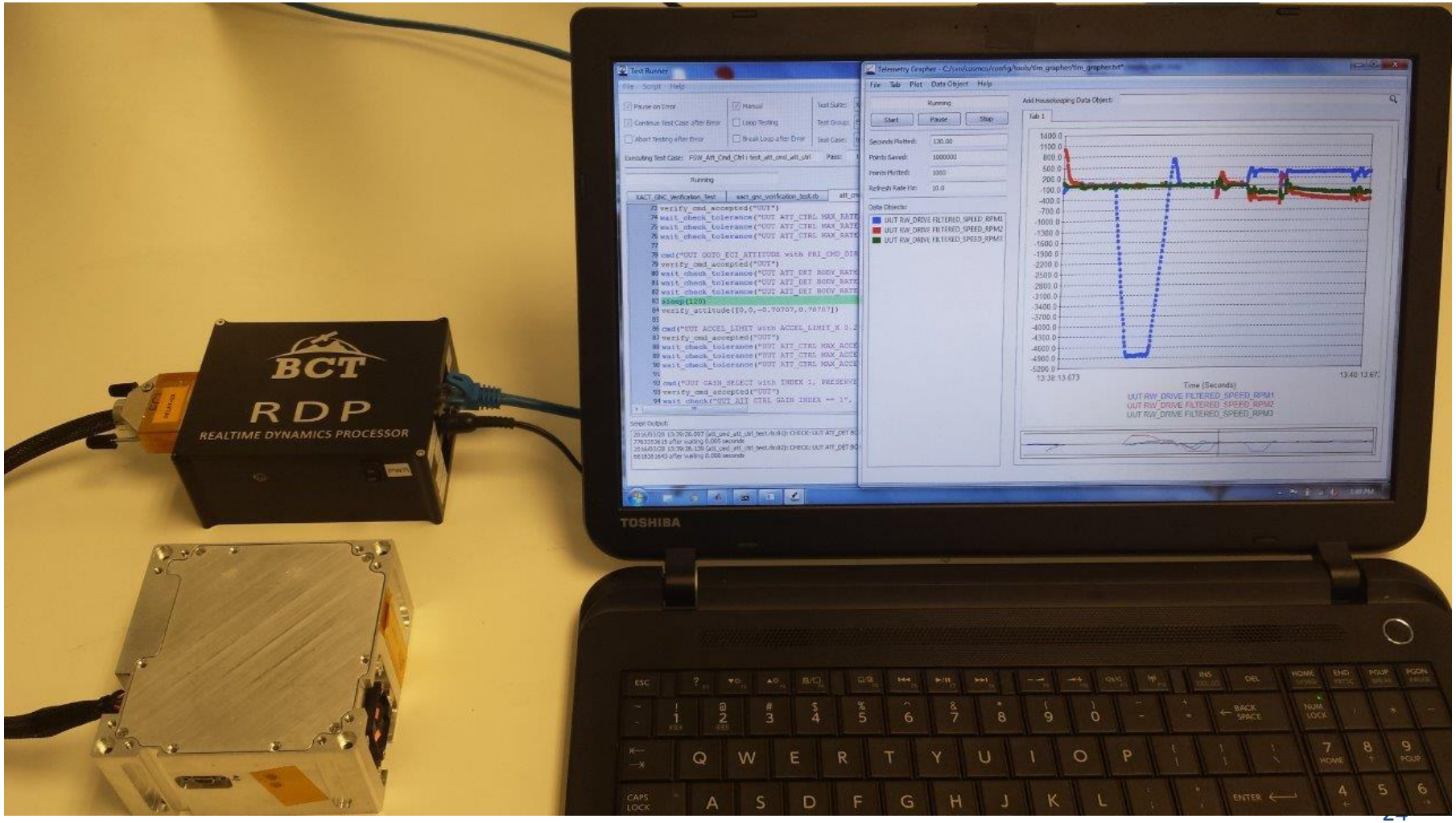
- BCT uses proven method for software development, which is extremely efficient, robust, and supports near-100% code re-use across all spacecraft.
- Developed by highly-experienced GN&C and software personnel, having worked over 20 spacecraft programs at a variety of companies, prior to BCT.
- Capability-rich software goes far beyond most cubesats and microsats, and is on-par with tier-1 spacecraft.
- Over 90% of flight software is auto-coded using Matlab/Simulink.
- One of the most advanced spacecraft auto-code systems in the industry.
- Common core for all Blue Canyon Technologies software products.
- Automated code generation and build process substantially reduces effort over traditional methods.

# Standard Flight Software Features

- Multi-rate System with real-time OS
- Commands (real-time, stored)
- Telemetry (multiple selectable maps)
- Fault Protection & Autonomy
- Table Management
- Time Keeping
- Attitude Orientation Command
- Attitude Determination & Control
- Orbit Propagation
- High-precision reference vectors
- Wheel Control, including high-speed servo loop
- Momentum Control (magnet and/or thruster)
- Thruster Control
- Solar Array Drive Control
- SD card file storage and playback
- Radio device operation
- Payload interfaces (custom processing as necessary)

# Fully automated, scripted, closed-loop testing

- "Test as you fly" capability

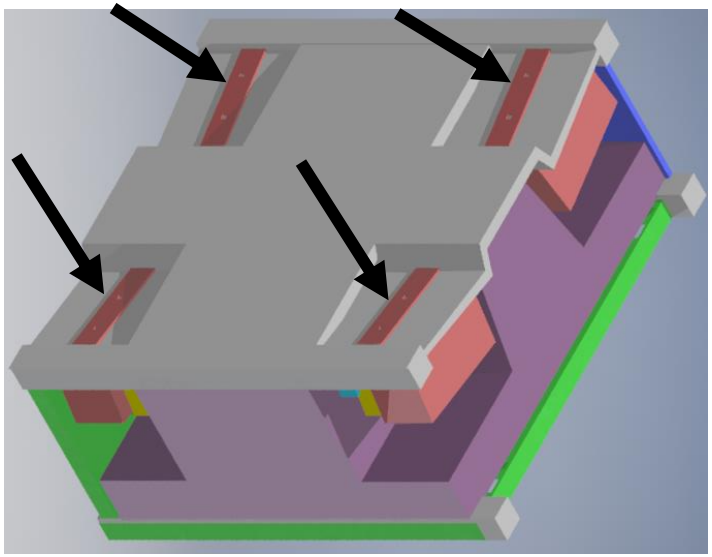


# Propulsion

- XACT/XB1 algorithms augmented to support propulsion/momentum control for JPL MarCO mission
- XACT/XB1 is compatible with multiple propulsion systems
- Currently using VACCO cold gas, and Fluid & Reason Iodine EP (ConstantQ)

# ConstantQ Electric Propulsion

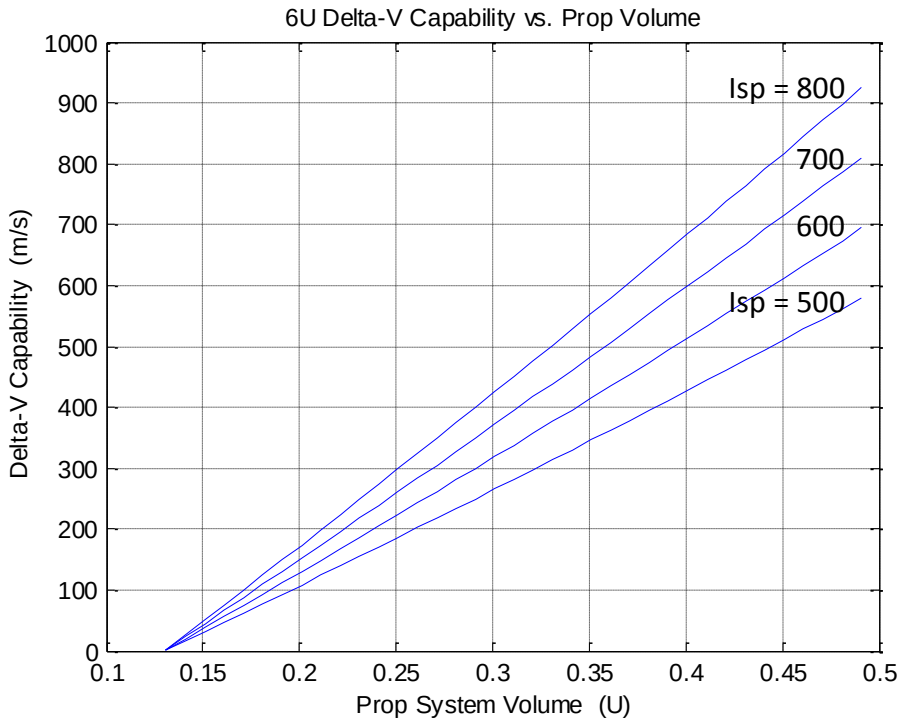
- Compact Iodine fuel
- High-efficiency electric propulsion (est. Isp: 600-800 s)
- Comparatively high thrust (1.5 mN each)
- Comparatively low power (20W for 4 thrusters)



Four thrusters, each with triple in-line valves.

Canted thrusters allows 3-axis attitude control.

Unit under test at Georgia Tech



# Particles (i.e. radiation)

- BCT implements a radiation screen and qualification program for EEE parts used in any BCT product which includes
  - Total Ionizing Dose (TID) testing
  - Proton testing
  - SEE testing / characterization / upset rate
  - SEL immunity
- Testing is performed at test facilities including JPL, TRIUMF, JHU/APL, UC Davis, and TAMU
- Through the RS-COTS program, BCT products are reliable in the space radiation environment, with typical mission life durations (including Radiation Design Margin of 1.5) as shown in the table below

| Mission Orbit | Mission Life in Years (including Radiation Design Margin = 1.5) |
|---|---|
| LEO (ISS) | 16 |
| LEO (600km, Sun Sync) | 5 |
| LEO (800km, Sun Sync) | 3 |

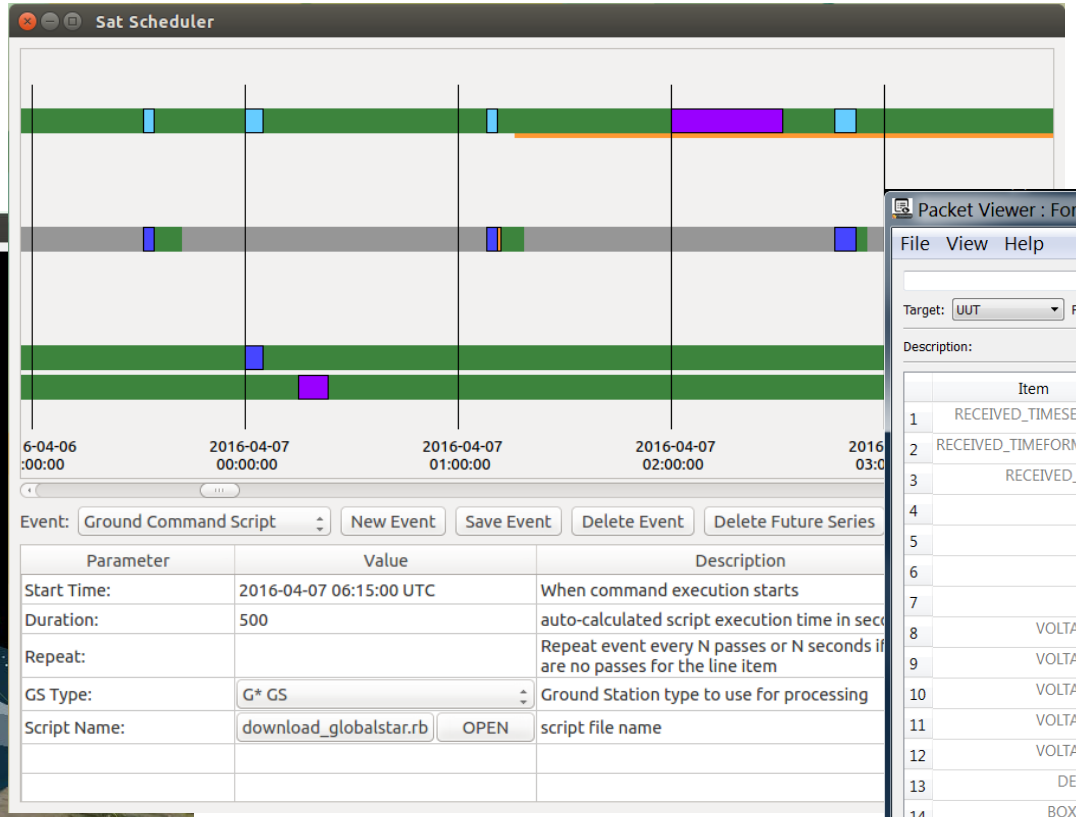
# Propagation of command & telemetry (i.e. comm)

- XB1 is compatible with a variety of command and telemetry devices
  - UHF: 9.6 kbps to 3 Mbps
  - S-Band:  1Mbps to 5 Mbps
  - X-Band:  >10 Mbps
  - Globalstar: valuable for high availability communication
  - Laser Comm
- BCT provides Mission Operations and can support operations with multiple ground stations
  - BCT rooftop antenna supports low data rate UHF
  - Near Earth Network
  - Commercial ground station providers

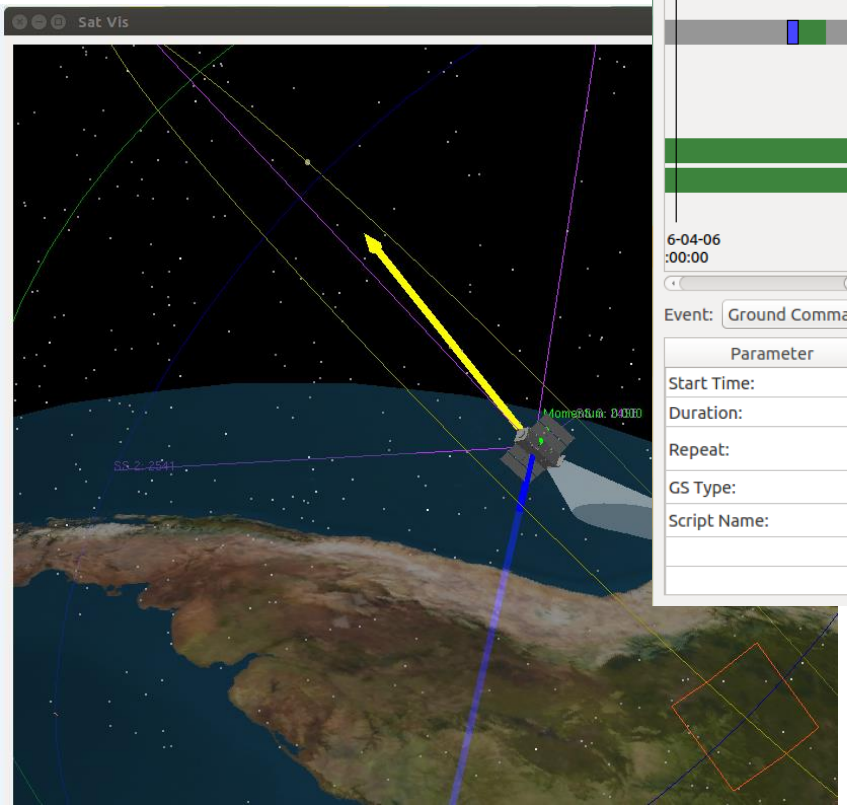
# Planning & Tasking (i.e. operations)

- BCT will be operating at least three spacecraft, near term
  - RAVAN
  - TEMPEST-D
  - Cube-RRT

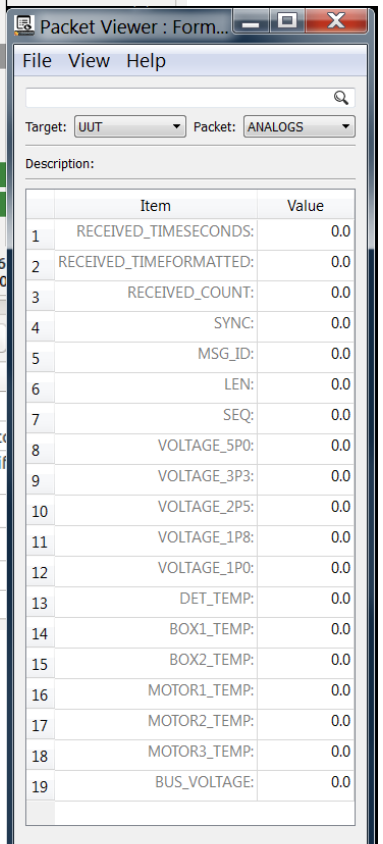
Event Scheduler




Satellite Visualization




Telemetry displays



# Flexbus Summary

- Highly configurable turn-key systems
- High performance
- High payload volume
- High payload power
- Highly experienced team

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