BLUE CANYON TECHNOLOGIES

Spacecraft Buses, Systems & Solutions

Recent Flight Experiences of Blue Canyon Technologies Spacecraft and Components

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BCT Product Overview

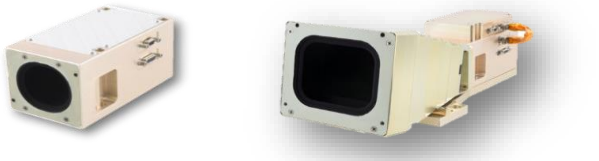
Components

Reaction Wheel Family

RWP015 0.015 Nms
RWP050 0.050 Nms
RWP100 0.10 Nms
RWP500 0.50 Nms

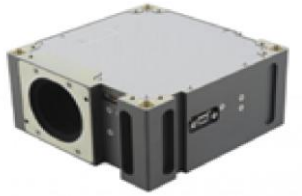
RW1 1.0 Nms
RW4 4.0 Nms
RW8 8.0 Nms

Star Tracker Family



NST
Extended Baffle NST

ADCS Systems



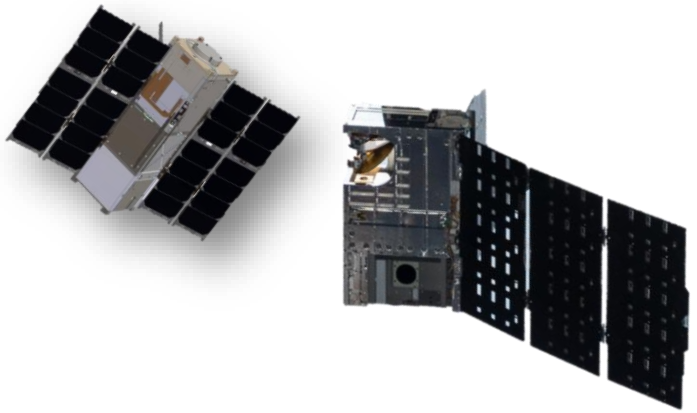
XACT
- 3 P015 Wheels
- Torque Rods
- Avionics

XACT-50
- 3 P050 Wheels
- Torque Rods
- Avionics

FlexCore
- Up to 4 Wheels
- Torque Rods
- Avionics
- Up to 2 Star Trackers

Spacecraft

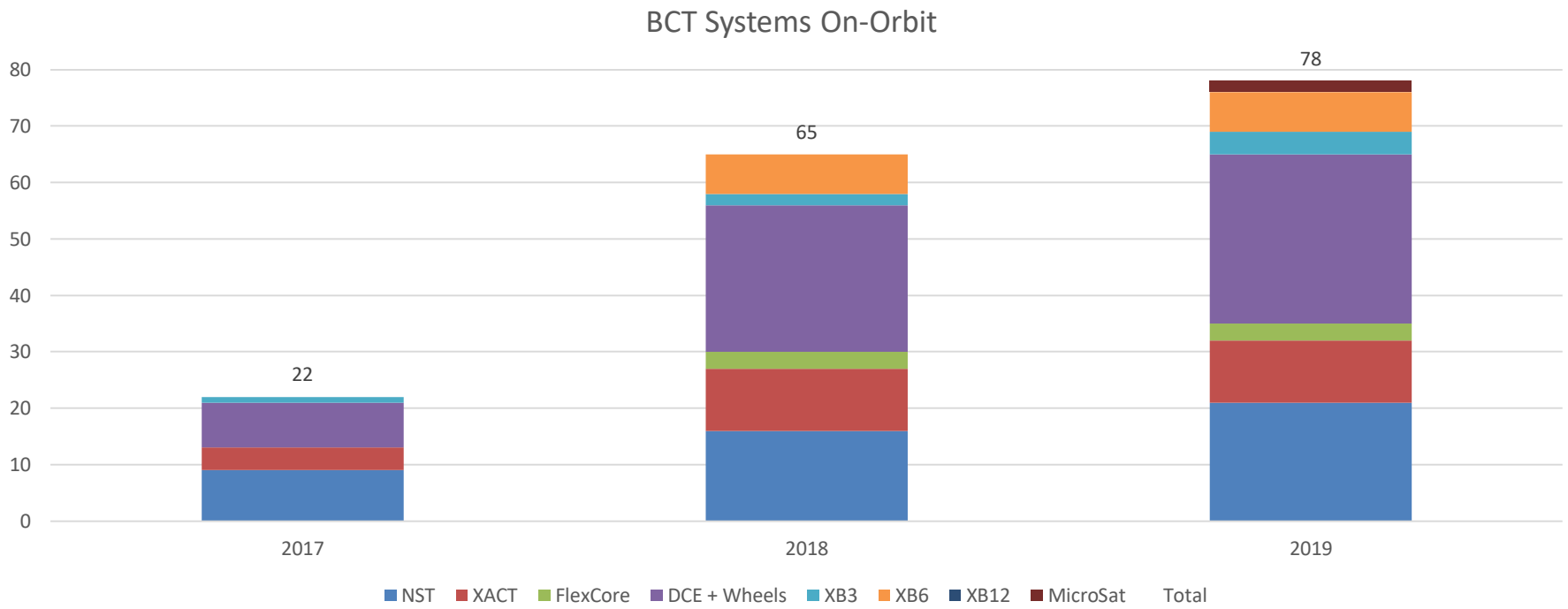
CubeSats (3kg – 16kg)



MicroSats (20kg – 150kg)

Current Snapshot of On-Orbit Heritage

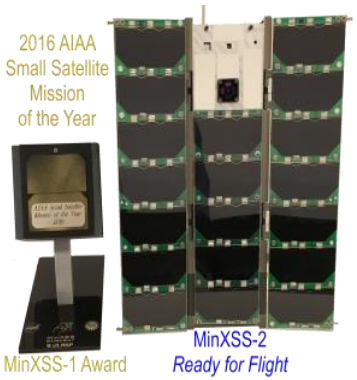
- 13 XB-based spacecraft
  - 2 MicroSats
- 27 Complete ADCS
- 54 Nano Star Trackers (21 stand-alone units)
- 172 Reaction Wheels
- On vehicles ranging from 3U CubeSats to 150 kg MicroSats to externally mounted on ISS
- LEO to GEO to Interplanetary



MinXSS (2016-2017) & MinXSS2 (2018-2019)

- LASP 3U CubeSats to study X-Ray Emissions from Sun
- MinXSS1 won the 2016 AIAA Small Satellite Mission of the Year award
  - Deployed from ISS May 2016; de-orbited May 2017
  - LASP's MinXSS was the first flight of any BCT product
- MinXSS2 deployed from SSO-A launch December 3, 2018
  - MinXSS2 first light captured December 7, 2018, just 4 days after launch
- BCT provided complete ADCS solution in the 0.5U XACT form factor
- Pointing performance results correlate well with MinXSS SPS data, ground-based night sky tracker testing, and on-orbit XACT-reported control errors
- LASP able to produce meaningful science data from observed solar flares

MinXSS1 Award and MinXSS2 Photo



MinXSS2 First Light

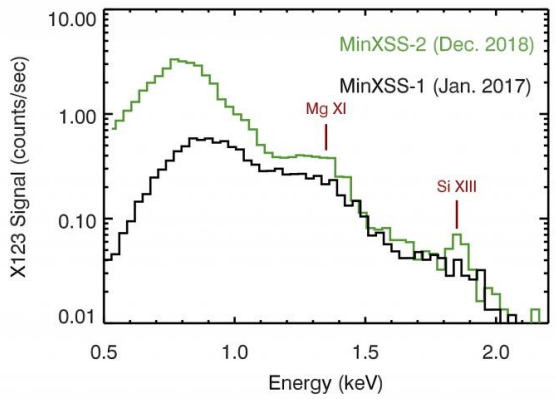
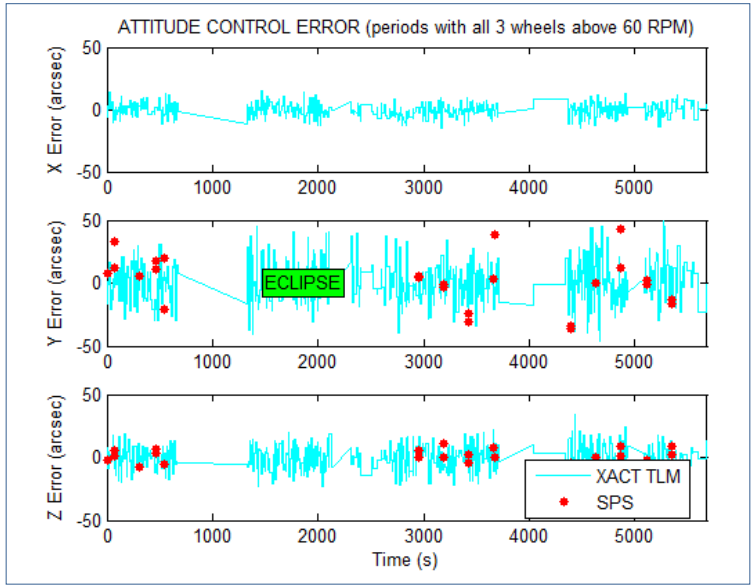


Image Credits: LASP

Data from MinXSS1 mission

Body Axis	RMS Error (asec)		
	Per XACT	Per SPS	Spec
X	5.3	n/a	11
Y	15.8	20.1	25
Z	9.4	6.8	11



ASTERIA (2017-)

- NASA JPL satellite to observe exoplanets in a 6U CubeSat form factor
  - Deployed from ISS November 2017; still in orbit today
- BCT provided 0.5U XACT attitude control system with low-jitter p015 reaction wheels
- First sub-arcsecond pointing performance in a CubeSat
  - Won the 2018 AIAA Small Satellite of the Year award

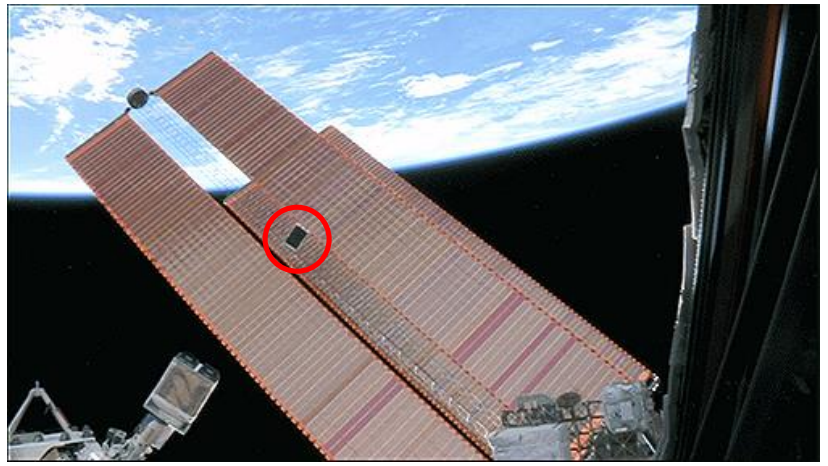


Image Credit: NASA

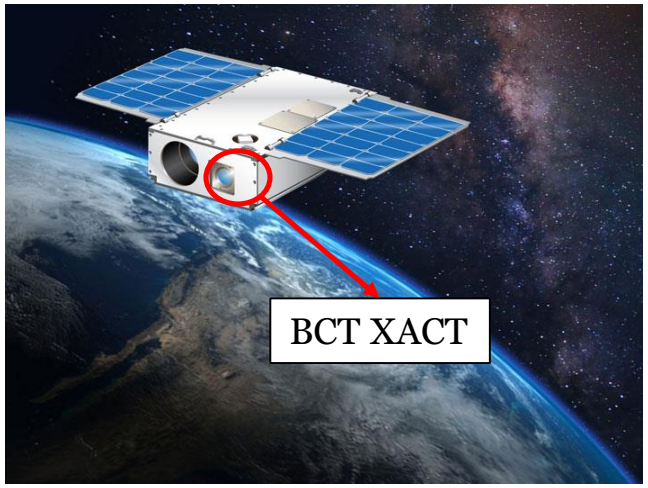


Image Credit: NASA/JPL - Caltech

- JPL-developed fine steering mirror enhanced XACT's native 1.6 arcsecond RMS stability to provide a total 0.5 arcsecond RMS pointing capability
- Spacecraft-level thermal changes caused low frequency alignment drift between XACT and payload frames
- Spacecraft-level magnetic dipole was larger than the dipole of 1 XACT torque rod; XACT still able to successfully maintain momentum
- Demonstrated capability for CubeSats to provide valuable astronomical measurements

MarCO (2018-2019)

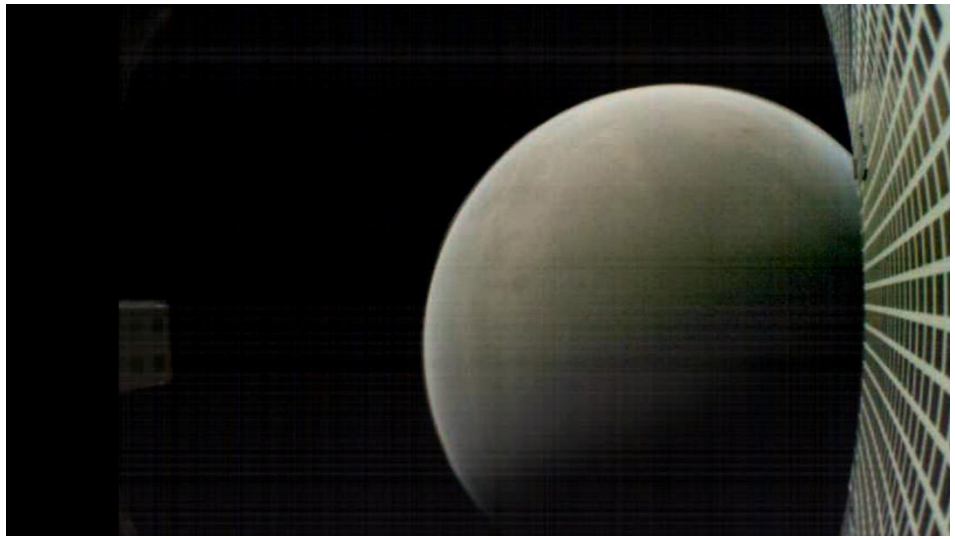


Image Credit: NASA/JPL - Caltech

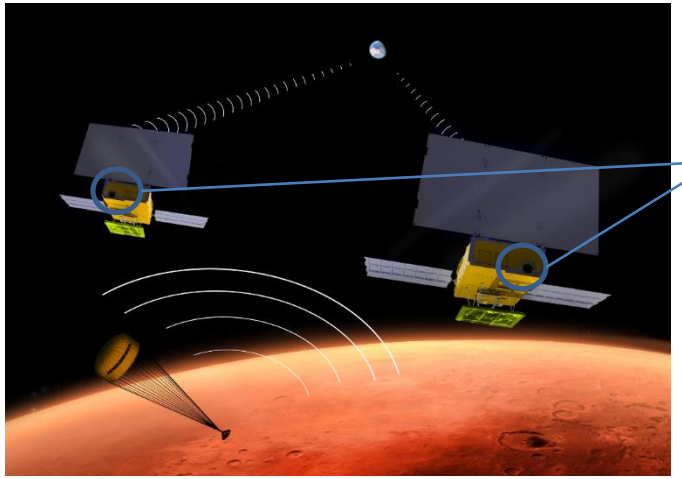


Image Credit: NASA/JPL - Caltech

MarCO XACTs

- First interplanetary CubeSats that accompanied the Mars Insight Lander
- Provided 2 XACT attitude control systems for the pair of 6Us
  - Star tracker, reaction wheels for attitude control, thruster algorithm control, navigation, etc.
- First complete XACT units delivered for flight from BCT
- Successfully relayed real-time EDL data from the Insight lander back to the JPL on November 26, 2018
- No dropped data during the EDL portion (except during an expected outage from Insight), indicating ADCS maintained the correct attitude through the event
- Demonstrated capability of CubeSats as inexpensive “tag-alongs” to bigger spacecraft/landers during interplanetary missions
- XACT algorithms operated thruster unit to provide trajectory correction burns with 3-axis attitude control and momentum control operations

Other Spacecraft Components (2016-)

STP-H5

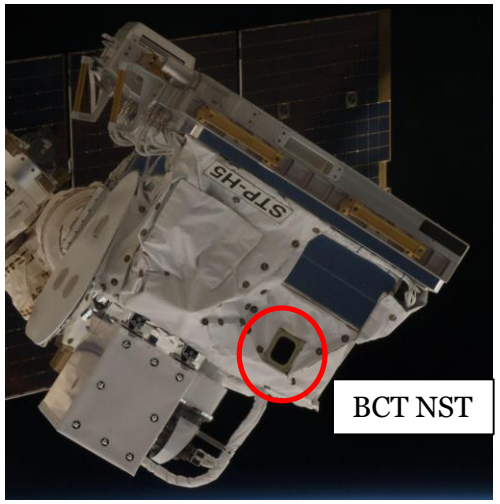


Image Credit: NASA

CYGNSS Spacecraft

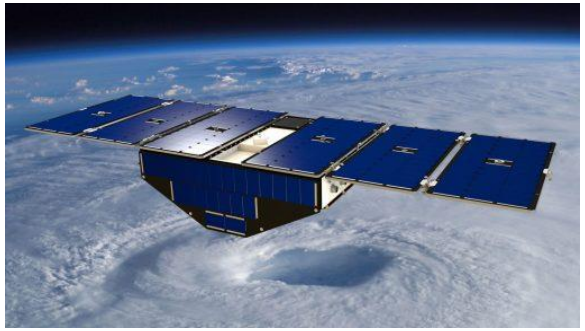


Image Credit: NASA

- Supported the NASA CYGNSS constellation, STP programs, and other commercial partners by providing individual ADCS components
  - NASA CYGNSS constellation won the 2017 AIAA Small Satellite of the Year award
- BCT providing star trackers, reaction wheels, and drive electronics for large constellations
- BCT hardware was present on 11 out of the 64 small satellites on the SSO-A launch in December 2018
- Modern drive control boards have extremely low power to meet limited power budgets of CubeSats
- BCT automation methods allow for rapid production, test, and delivery
- Same components that go into BCT-built spacecraft; high re-use allows for lower costs and better understanding of components

TEMPEST-D/HaloSAT/CubeRRT (2018-)

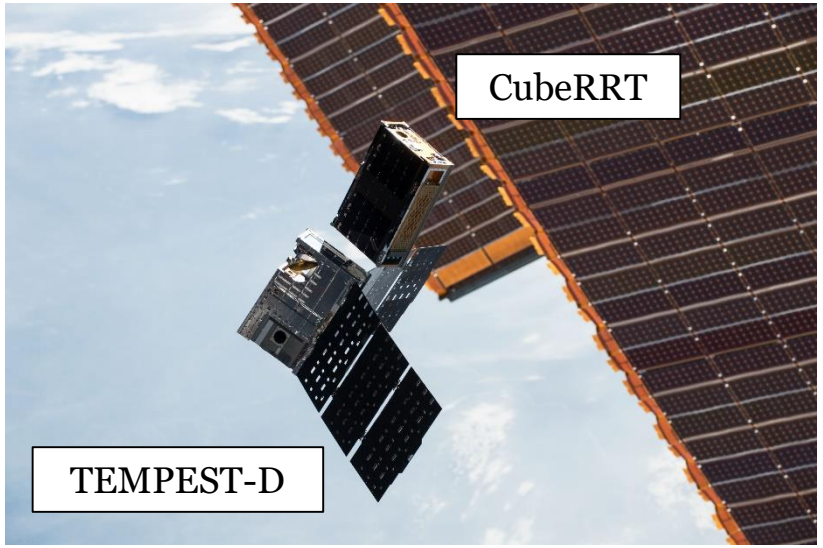
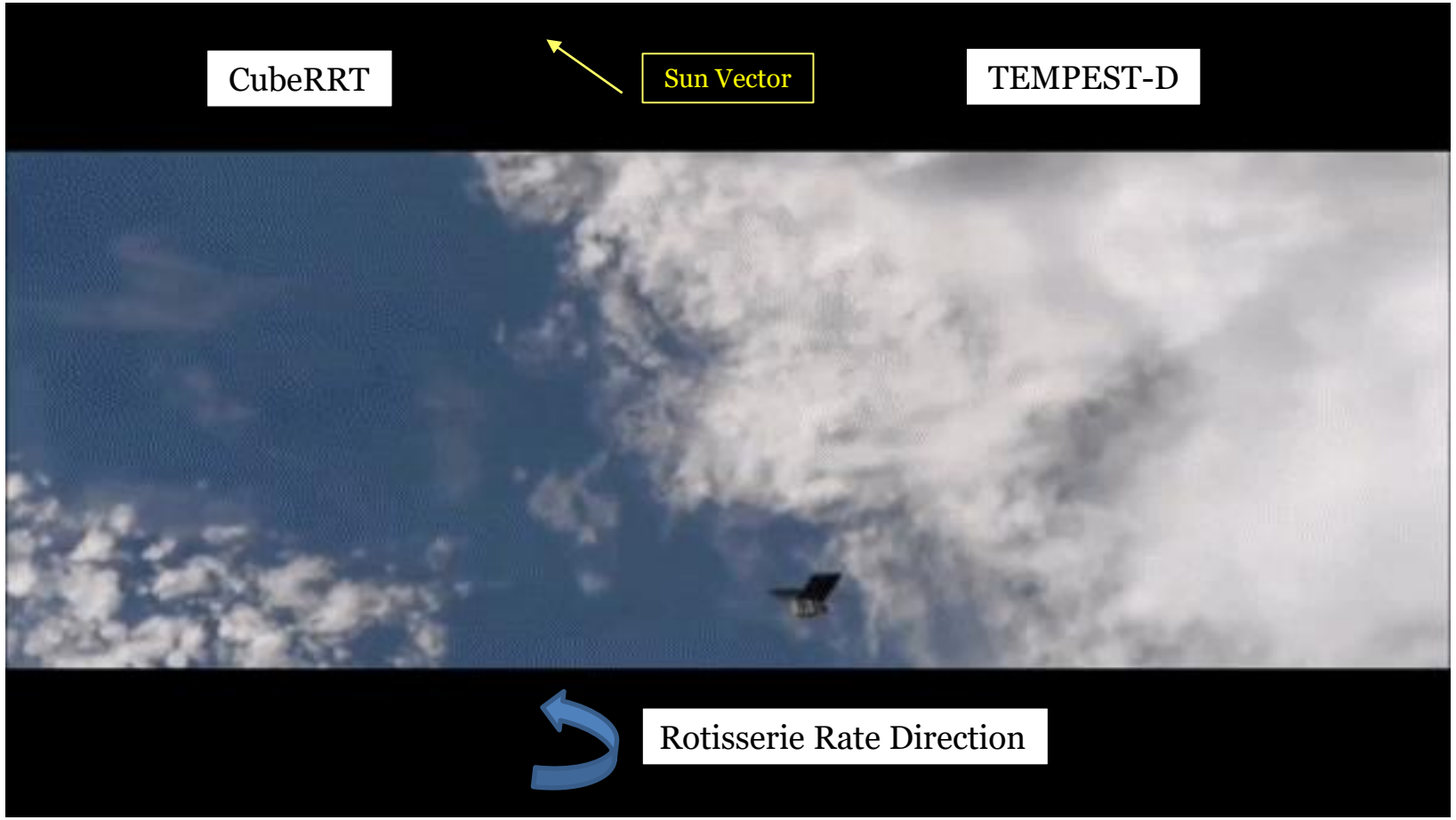


Image credit: NASA/JPL-Caltech

Image credit: NASA/JPL-Caltech

- All 3 spacecraft deployed from the ISS on July 13, 2018
  - All spacecraft built by BCT, performed system integration and test of the spacecraft, performing operations out of BCT
- Due to ground station issues, could not establish reliable comms with spacecraft for 4 weeks
- Once communication was established, shown that spacecraft were healthy and autonomously pointing at the sun waiting for commands
- **Highlights importance of robust safe mode on small satellites to allow ground time to debug and troubleshoot**
- Due to spacecraft sharing a single antenna with other satellites, severely limited in contact times until spacecraft naturally became separated in-track
- Maneuvered the spacecraft to control drag to separate the spacecraft to increase the amount of available passes
- All spacecraft underwent successful commissioning and moved to payload/science operations

TEMPEST-D/HaloSAT/CubeRRT (2018-)

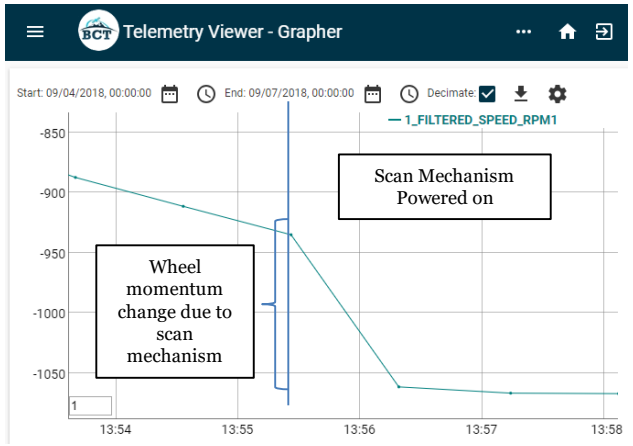


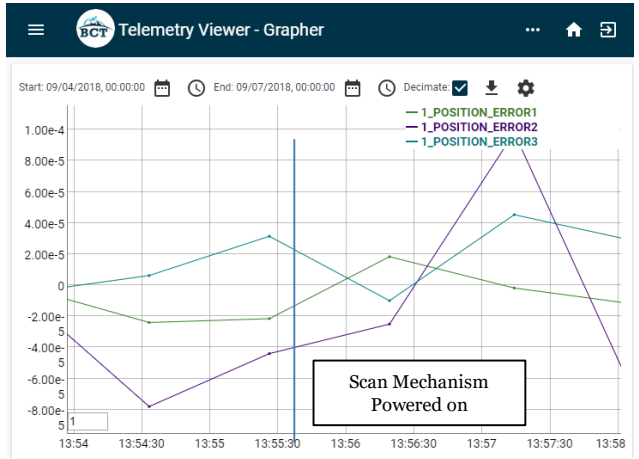
Video Credit: NASA / NanoRacks

- Confirmed via ISS video footage spacecraft safe mode converged on the sun within minutes after deployment
- ISS video footage shows spacecraft happily performing rotisserie, awaiting commanding from the ground
- CubeRRT following planned deployment sequence of waiting 30 minutes before array deployment. Found the sun in < 1 minute after deployment
- Tempest-D solar arrays deployed in canister; mechanically held in place until spacecraft deployment

TEMPEST-D (2018-)

- NASA JPL funded mission to observe time evolution of clouds and conditions that create precipitating clouds
- Provided 6U bus, integration and test, and on-orbit operations
- Payload observed Hurricane Florence in the Atlantic and was able to compare with other weather satellite observations
- BCT designed and built the payload scan mechanism motor and control to rotate the payload antenna
- Observed scan mechanism momentum disturbance in reaction wheel on-orbit telemetry; confirming correct spin rate of the motor
- Attitude control sees slight disturbance due to scan mechanism torque
- Pointing performance (1σ) excluding wheel zero-speed crossings (< 50 RPM)
  - X axis: 3.4 asec
  - Y axis: 3.3 asec
  - Z axis: 2.4 asec





TEMPEST-D Observation of Hurricane Florence (colored) overlapped with NASA GOES image

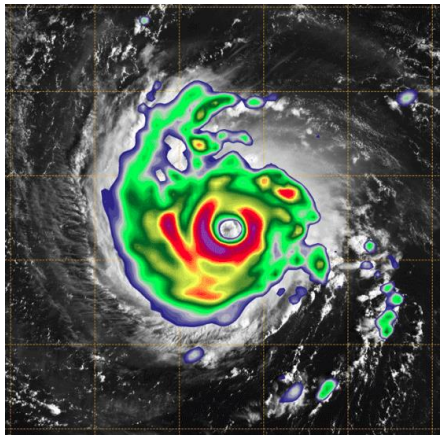


Image Credit: NASA JPL

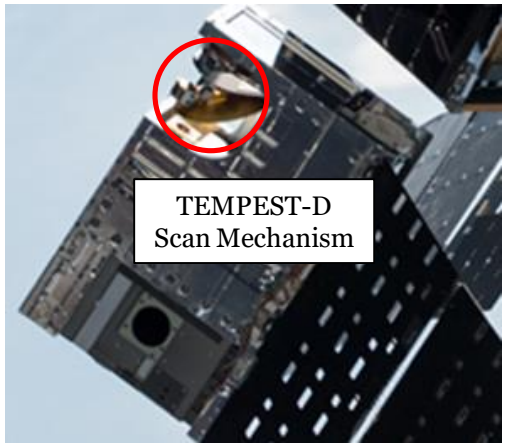


Image Credit: NASA

HaloSAT (2018-)

- University of Iowa and NASA Goddard funded 6U CubeSat to study missing matter in the halo of gas surrounding the Milky Way
- BCT provided the bus, spacecraft integration and test, and operations for the mission
- Requires precision knowledge between spacecraft pointing and payload boresight vectors
- Performed complex payload calibration maneuvers against celestial targets using very fine precision, slow slews
  - Expect full response within 5 degrees, no response beyond 7 degrees of payload boresight
  - Allows characterization of any asymmetry and for boresight center with respective to payload center
- Currently working to support payload operations and observation targets
- Payload operations occur every orbit starting just before dusk terminator and ending just after dawn terminator
  - BCT developed optimal planning tools to observe targets given star tracker Earth keep out constraints
- On-orbit pointing performance enhanced by dual star trackers (1σ) excluding wheel zero-speed crossings (< 50 RPM):
  - X axis: 3.1 asec
  - Y axis: 3.0 asec
  - Z axis: 2.7 asec

HaloSAT First Light

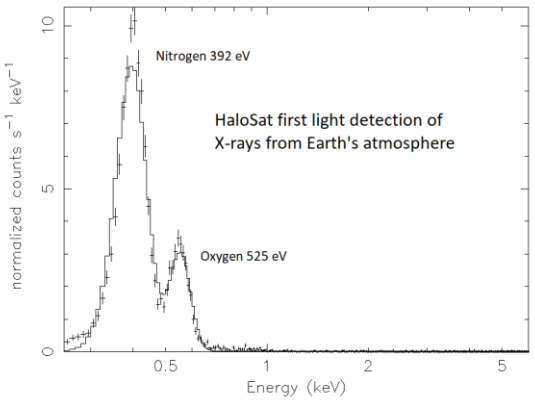
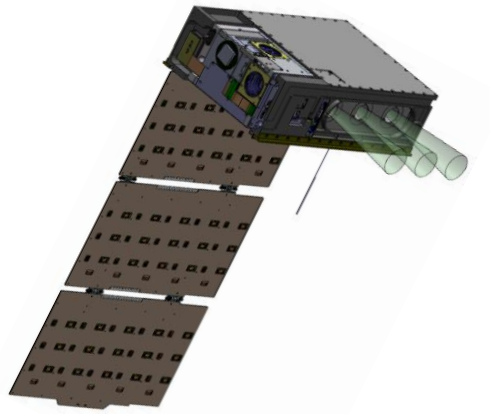


Image Credit: University of Iowa



HaloSAT Slew Test Results

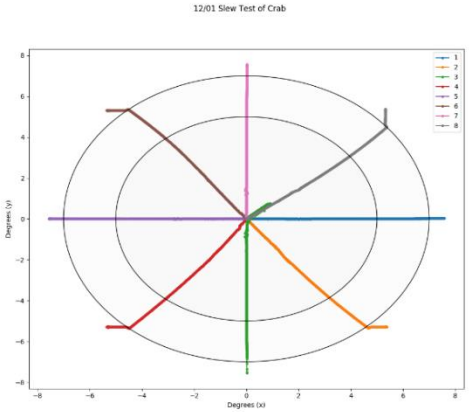


Image Credit: University of Iowa

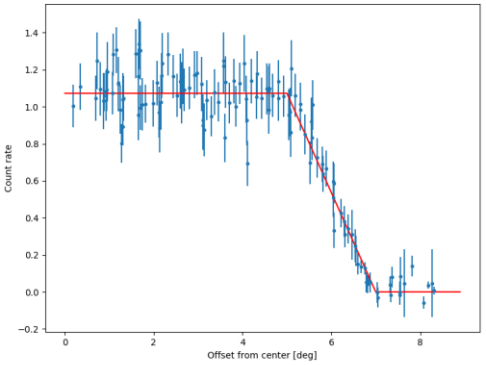


Image Credit: University of Iowa

MicroSats (2019-)

- Quantity 2 MicroSat buses on orbit in early 2019
- BCT provided control avionics, radio interface, reaction wheels, star trackers, EPS system, solar arrays, etc.
- Utilizes common internal components and software as all other ADCS and CubeSat products
- High component and software re-use maximizes heritage, minimizes development
- Configurable per mission needs

- S5 Spacecraft at GEO
  - BCT provided bus, integration and test services, and operations
- Space Situational Awareness mission

- R3D2 DARPA Spacecraft
  - BCT provided bus
- DARPA Spacecraft to qualify new membrane reflect-array antenna

Image Credit: Northrup Grumman

Upcoming On-Orbit BCT Operations (2019+)

- TROPICS Constellation
  - Constellation of 6, 3U, CubeSats for weather observations
  - BCT bus, System Integration and Test, and Operations
    - Utilizes BCT scan mechanism controller to spin payload during operations
    - BCT Solar Array Drive for optimum power generation during operations
- BCT also slated to delivery many additional units launching near-term

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Q&A

Further Questions?
Email me at clamkin@bluecanyontech.com

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