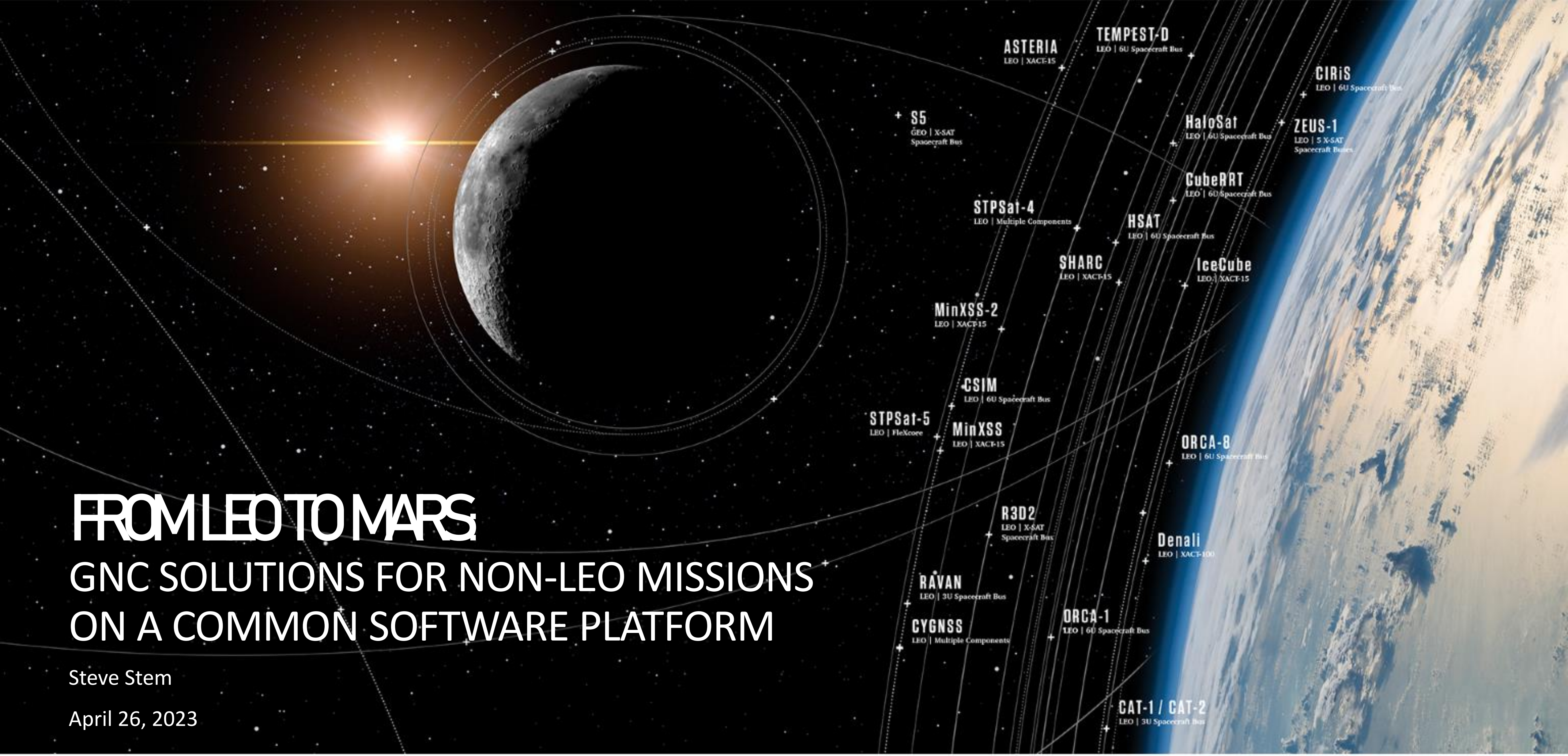


FROM LEO TO MARS:

GNC SOLUTIONS FOR NON-LEO MISSIONS ON A COMMON SOFTWARE PLATFORM

Steve Stem

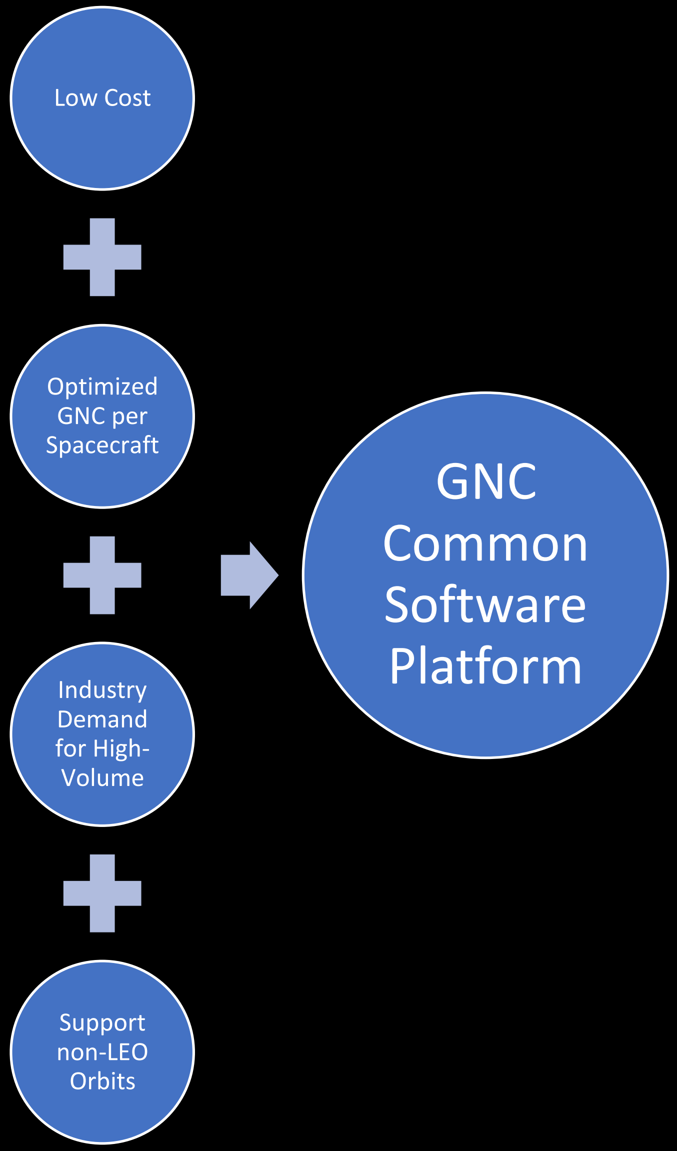
April 26, 2023

BLUE CANYON TECHNOLOGIES

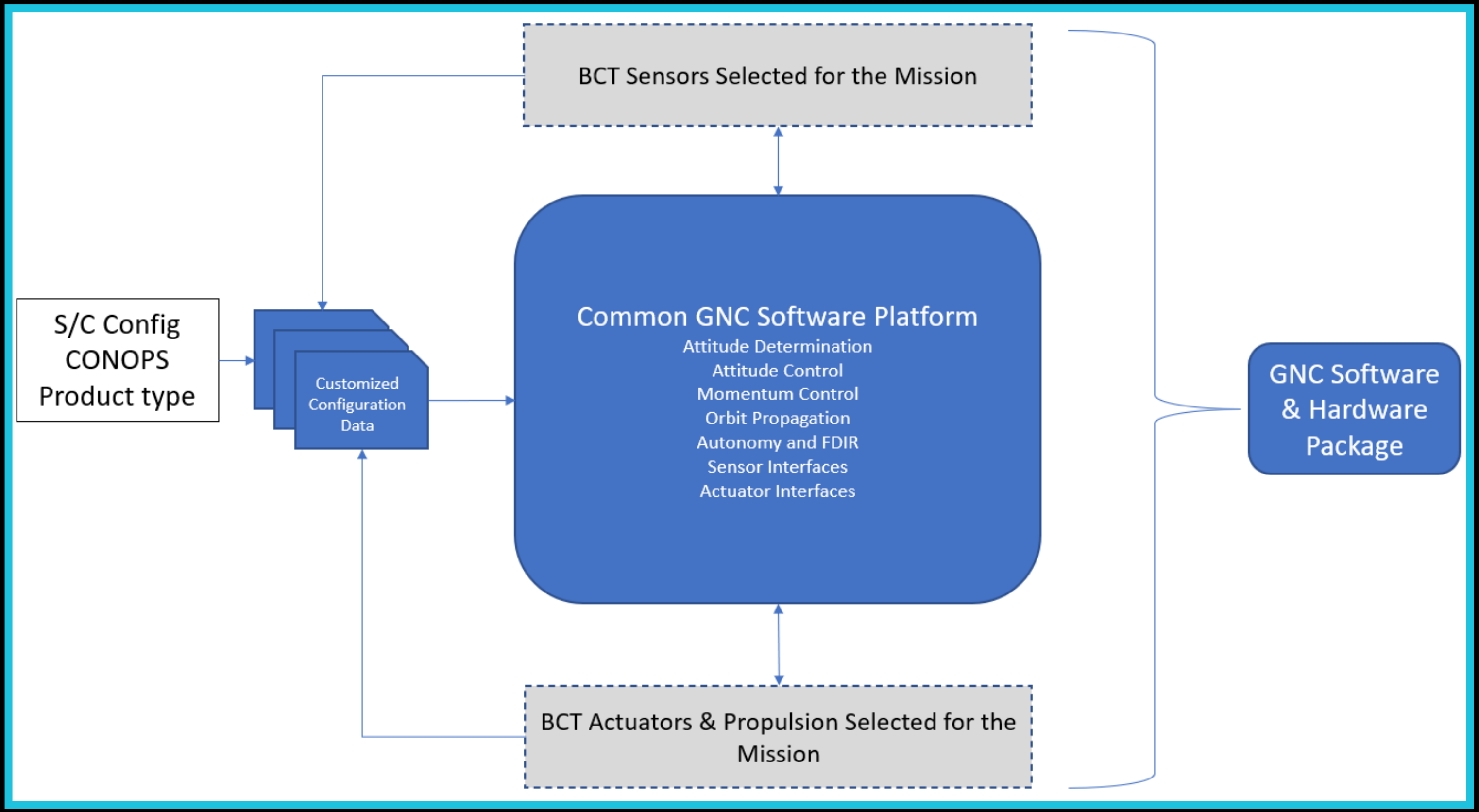
WARNING – This document does not contain technology or technical data controlled under either the U.S. International Traffic in Arms Regulations or the U.S. Export Administration Regulations.

PROBLEM OVERVIEW

- GNC subsystem often drives cost/complexity
- Industry looking for highly capable and optimized solutions for various spacecraft sizes/regimes
- Demand for high-volume GNC systems indicated by 50+ BCT GNC delivered systems per year
- Many small satellite ADCS systems assume a LEO orbit but there are opportunities for non-LEO missions



COMMON SOFTWARE ARCHITECTURE

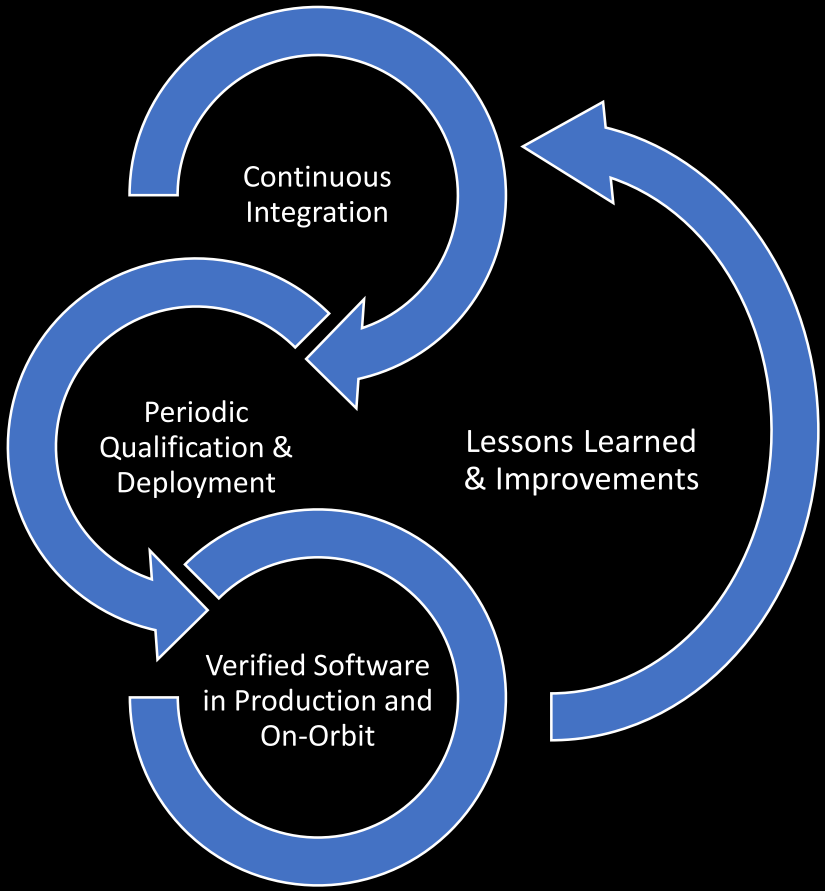


- Software architecture split between core algorithms and configuration data
- Core algorithms' behavior driven by mission-specific configuration data
- Combined with any BCT sensors/actuators, can be utilized for an unbounded set of hardware and spacecraft configurations

CONTINUOUS INTEGRATION AND PERIODIC DEPLOYMENT

- Improvements and new features are continuously integrated into the common codebase, concurrently improving all products
- Nightly software regression testing with SWIL simulations

- Periodic efforts to create production-qualified software
- Software tested on multiple products to verify embedded system



- Software deployed to production minimizes AI&T issues
- Lessons learned from AI&T and on-orbit performance are quickly and confidently integrated

- Provides high heritage for the software via multiple products and many launches per year

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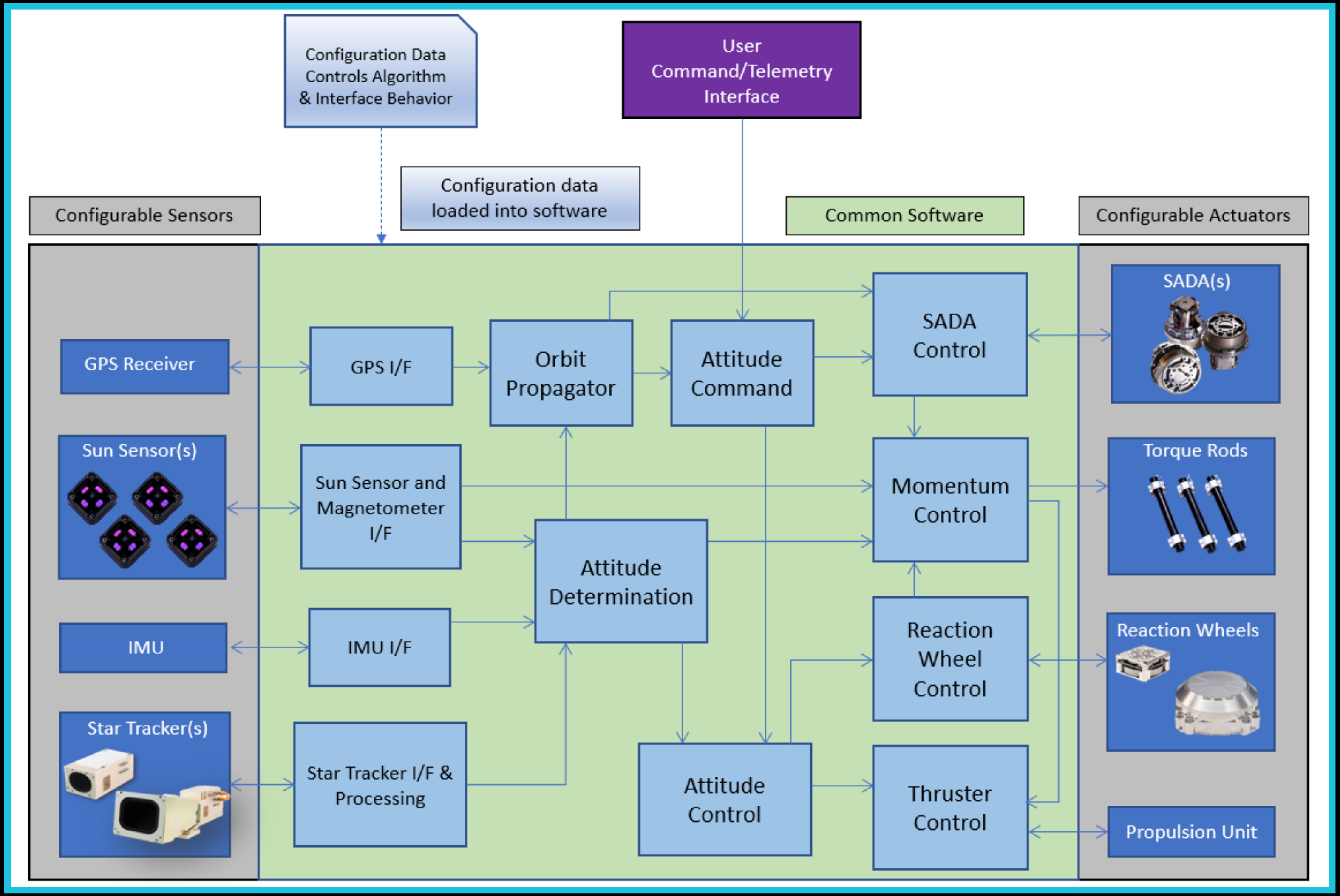
MODEL-BASED BLOCK DIAGRAM



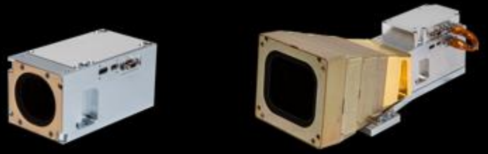
MULTIPLE PRODUCTS SUPPORTED

Components

Reaction Wheels

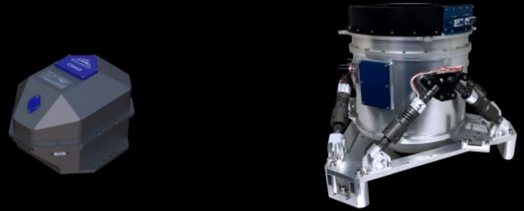
RW1 1.0 Nms | RW4 4.0 Nms | RW8 8.0 Nms

Nano Star Trackers



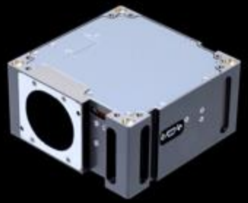
NST | Extended Baffle NST

Control Moment Gyros



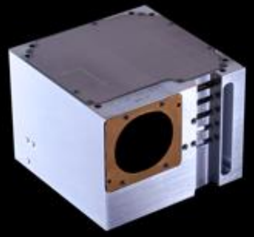
CMG-8 | CMG-12

ACS Systems



XACT
- 3 p015 Wheels
- Torque Rods
- Avionics

XACT-50
- 3 p050 Wheels
- Torque Rods
- Avionics

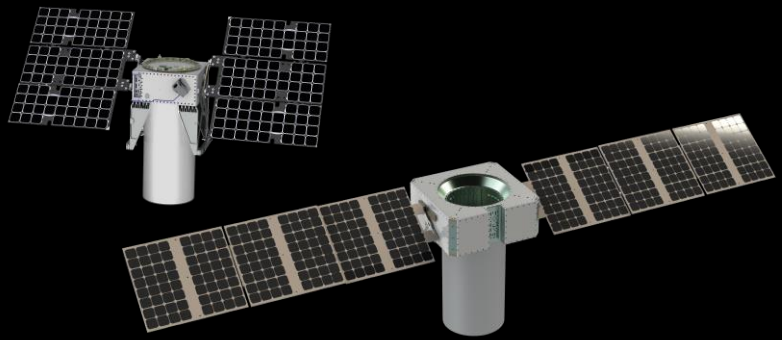


FleXcore
- Up to 4 Wheels
- Torque Rods
- Avionics
- Up to 2 Star Trackers

Spacecraft

CubeSats (3kg – 35kg)

Microsats (35kg – 450kg)



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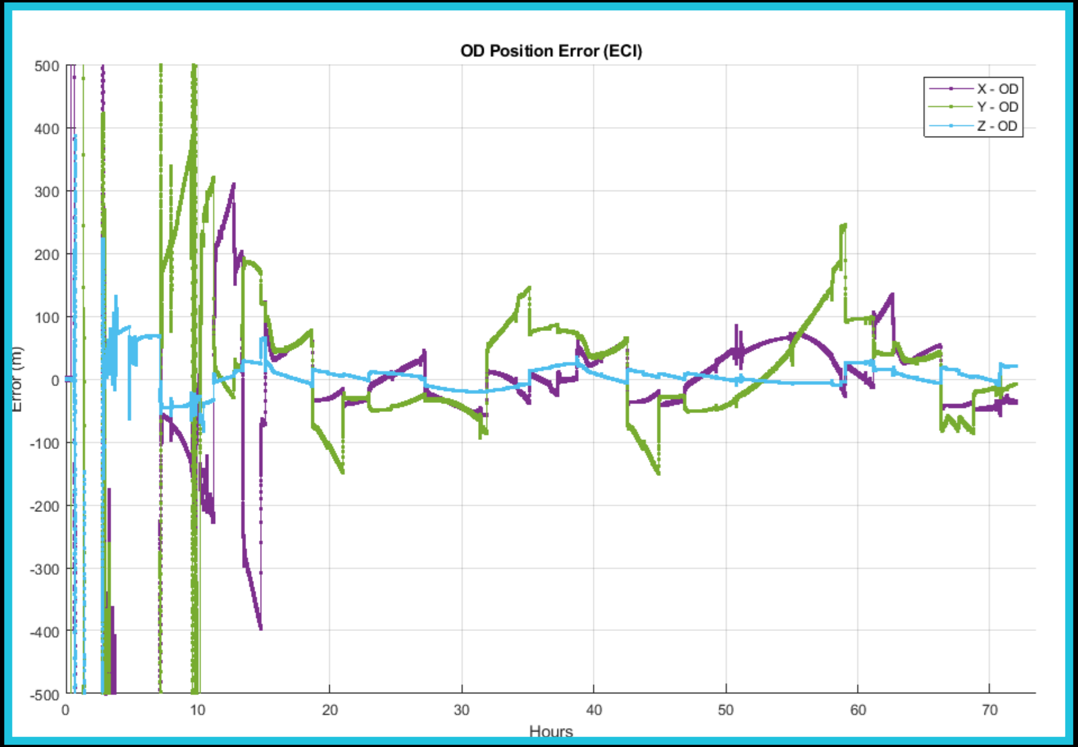
NAVIGATION SCHEMES

- Configurable software to select orbit determination approach:
  - GPS-based LEO orbit determination
  - GPS-based GEO orbit determination
  - User-provided trajectories
- Novel GPS at GEO approach shows total orbital knowledge on order of 100 meters using small satellite components
- User-provided trajectories supports systems and orbits where cost or size may lack PVT measuring devices

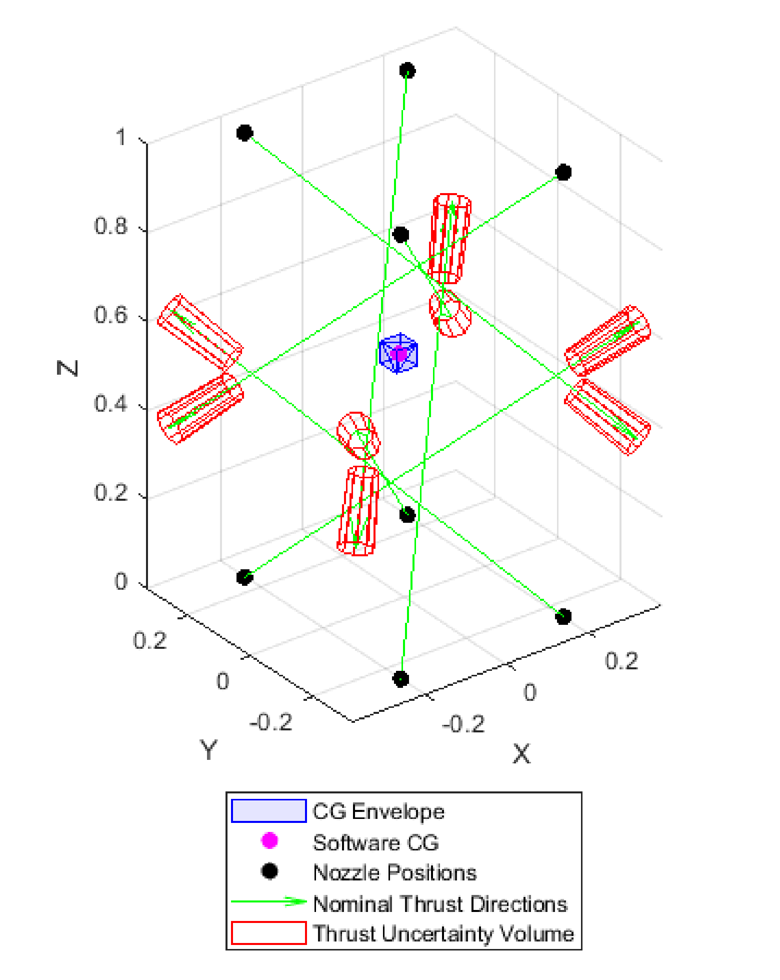


GPS at GEO Orbit Determination Performance
(HWIL simulation)

BLUE CANYON TECHNOLOGIES

ROBUST MOMENTUM CONTROL WITH THRUSTERS

- Momentum control achieved via propulsion beyond LEO orbits
- Uncertainties affecting thruster performance pose a significant challenge for small spacecraft
  - S/C CG Location
  - Effective thrust direction
  - Effective thrust magnitude
- BCT employs high-heritage methods to guarantee monotonic decrease in system momentum
  - Momentum controller robust to any credible combination of uncertainties
- GNC software supports full 6DOF control of spacecraft using thrusters
- Thruster control software architecture ensures robustness against erroneous or infeasible requests



IN-SITU AUTONOMY

- Limited ground contacts and constellation maintenance make on-board autonomy attractive
- GNC platform contains configurable features to enable autonomous recovery of sensors, actuators, or states
- Features are regularly tested both on-orbit and during AI&T through production line of multiple units
- Autonomous Mission Resume (AMR) capability can be utilized to recover spacecraft operational state and mission mode, even after a full software or hardware reset.

DEMONSTRATED PERFORMANCE – LEO

- 90+ independent spacecraft
- 2U CubeSats up to 200-kg spacecraft
  - Inertia range of 0.02 kg-m^2 to 400 kg-m^2
- Wide range of mission types:
  - Astrophysics
  - Meteorology
  - Heliophysics
  - Synthetic Aperture Radar (SAR)
  - University demonstrations

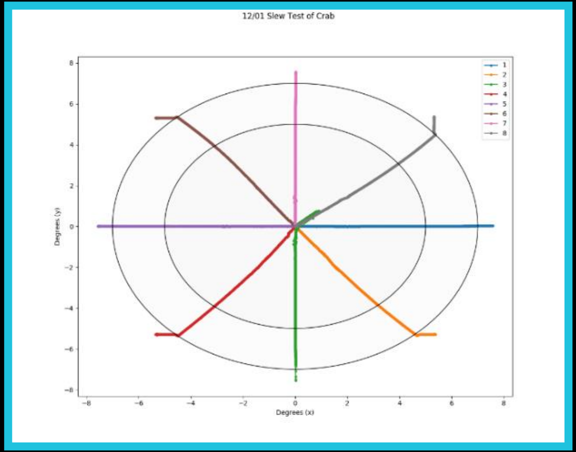
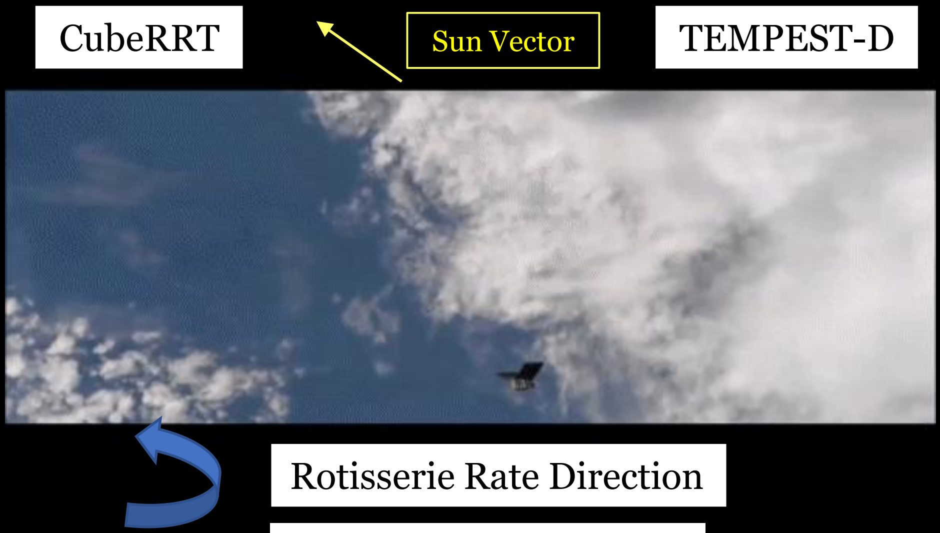


Image Credit: University of Iowa

Image Credit: NASA



Video Credit: NASA / NanoRacks

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DEMONSTRATED PERFORMANCE – BEYOND LEO

- ASCENT CubeSat deployed to GEO in 2022 with 10 more GNC systems delivered for GEO
- 10 missions beyond GEO:
  - Mars flyby
  - Asteroid flyby
  - Lunar orbit capture
- MarCO CubeSats:
  - First XACT delivered for flight from BCT
  - No dropped data during Insight EDL, indicating consistent ADCS performance
- Lunar Missions:
  - BCT GNC systems on 9 of 12 CubeSat missions launched last year

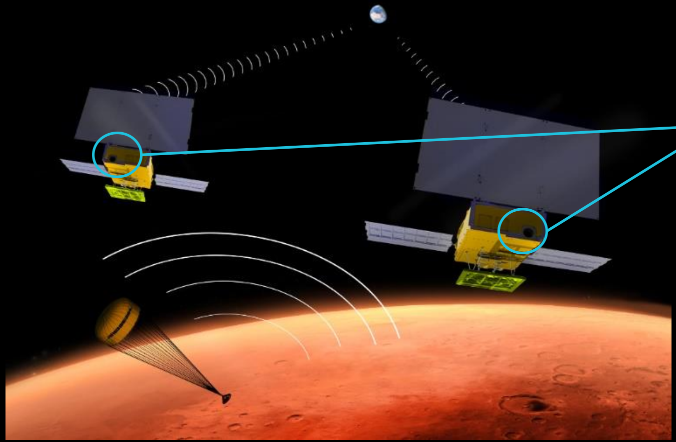
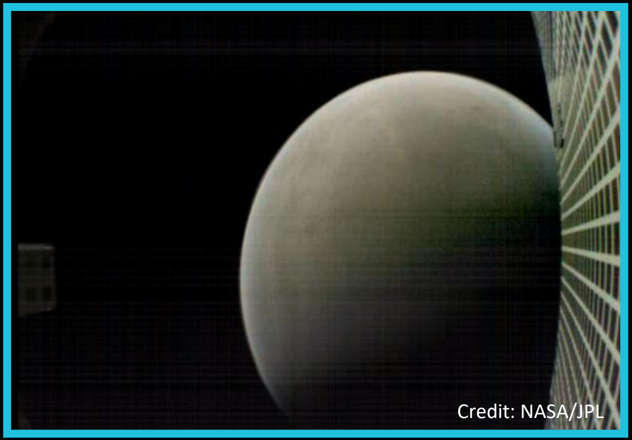


Image Credit: NASA/JPL - Caltech

MarCO XACTs

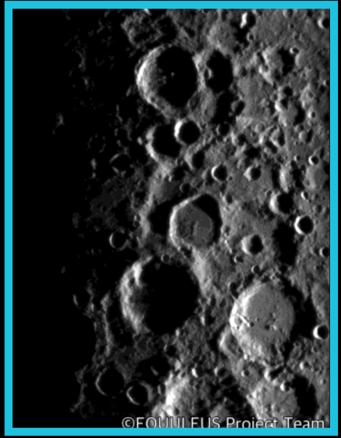


Credit: NASA/JPL

MarCO

Crediti: ASI/NASA

LICIACube



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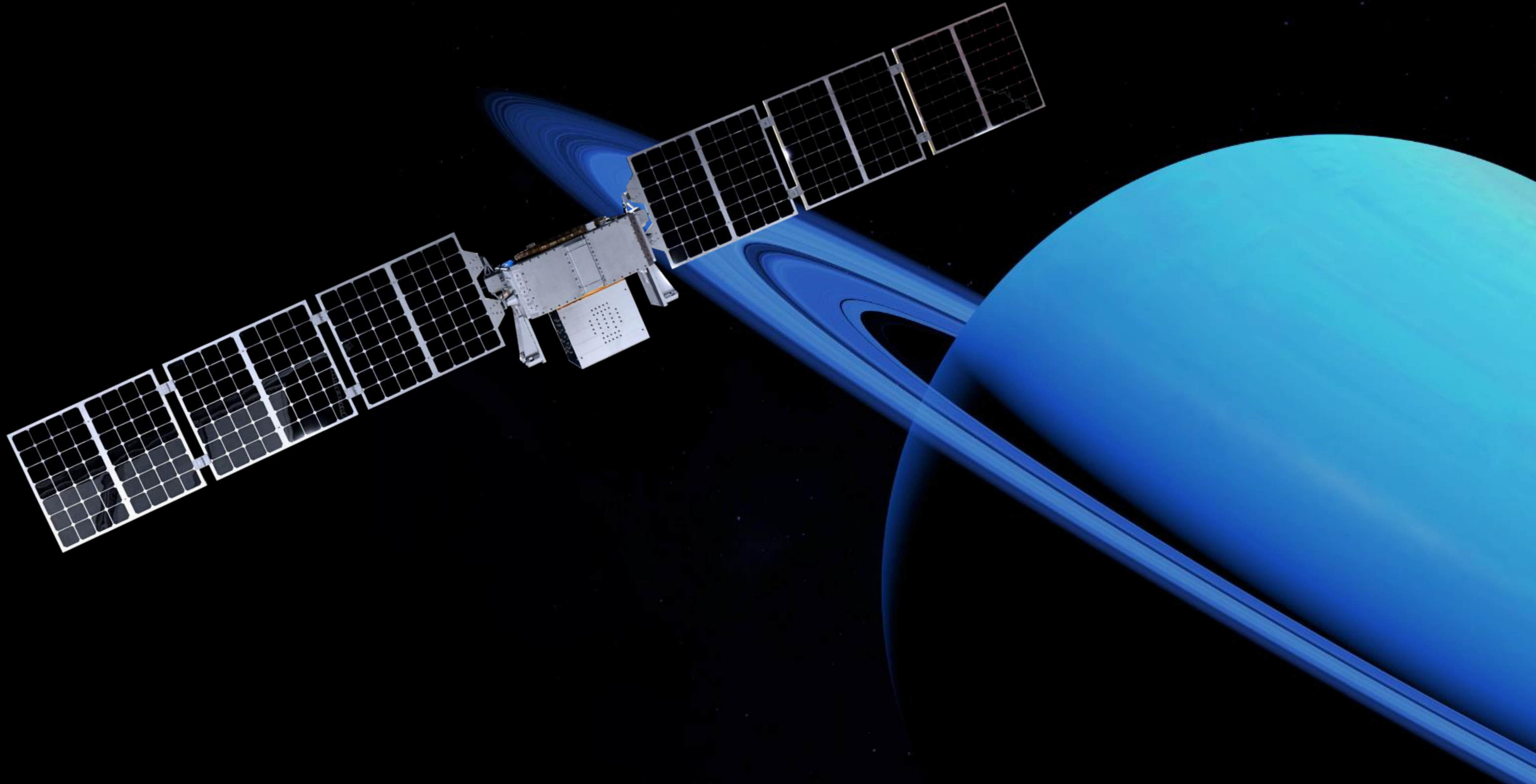
CONCLUSIONS & FUTURE WORK

- GNC common software platform has supported over 100 independent spacecraft on-orbit and many more through production and delivery
- High-heritage platform with successful non-LEO missions
- Other technological advancements for enhanced capability, such as autonomous orbit determination in cis-lunar orbit
- Industry continues to look for low-cost spacecraft to support high operational mission uptimes

Questions?



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THANK YOU