

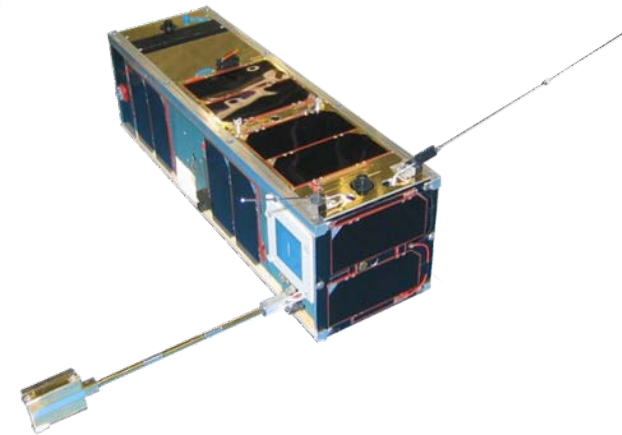
Canadian Advanced Nanospace eXperiment 2 Orbit Operations: One Year of Pushing the Nanosat Performance Envelope

Karan Sarda

Cordell Grant, Stuart Eagleson
Daniel D. Kekez, Amee Shah
Robert E. Zee

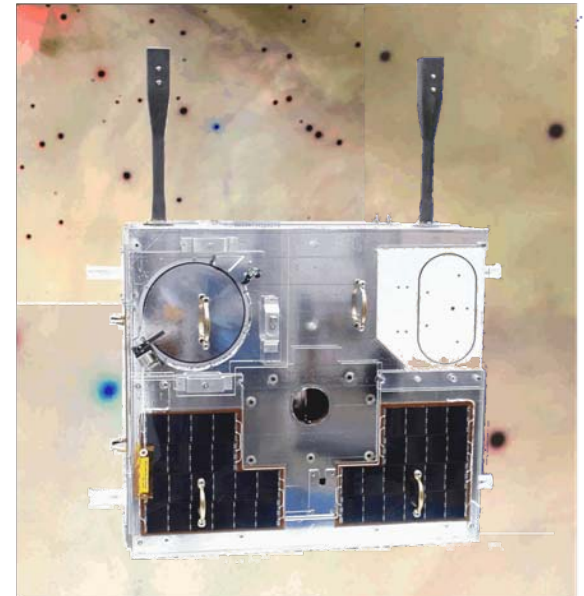
Space Flight Laboratory
University of Toronto

11 August 2009



Space Flight Laboratory

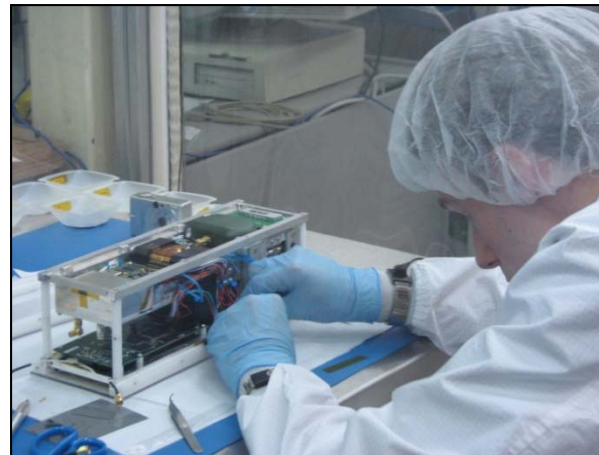
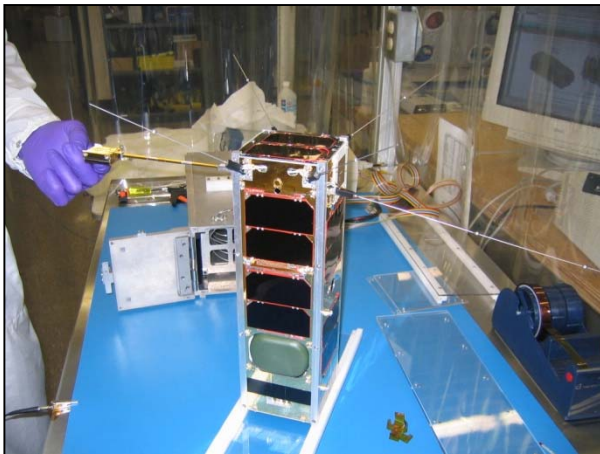
- SFL, founded in 1998
 - 15 engineering staff
 - 15 graduate students
- MOST: Canada's First Space Telescope
 - Long duration stellar photometry
 - 60-kg microsatellite
- CanX Program: Nanosatellites (1-7 kg)
 - Highly capable
 - Quick-to-launch (1-3yrs)
 - Tight budget
 - Modular/heritage-based design



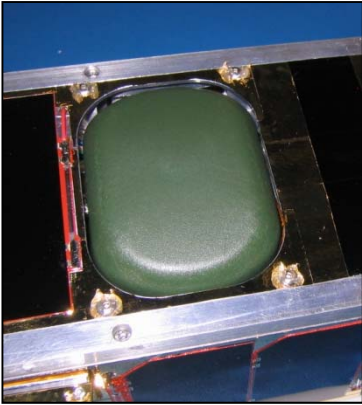
CanX-2 - Mission

Mission Goals:

- Technology demonstrator for future SFL spacecraft
 - Evaluate technologies critical for formation-flight
- Test-bed for scientists & researchers
 - Demonstrating cost-effective access to space



Technology Demonstration



GPS Hardware



Sun Sensors &
magnetometer



Reaction Wheel



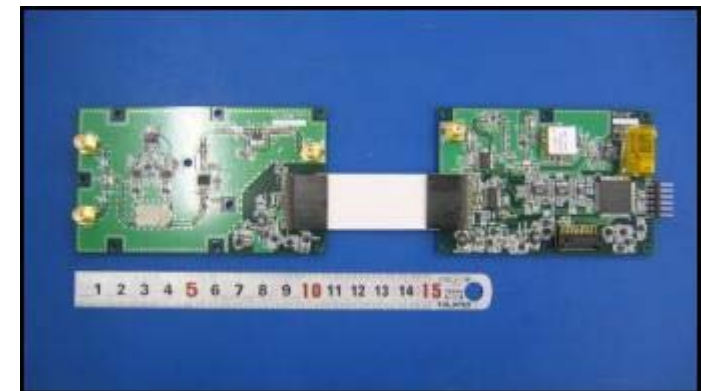
NANO Propulsion System (NANOPS)



On-Board Computer



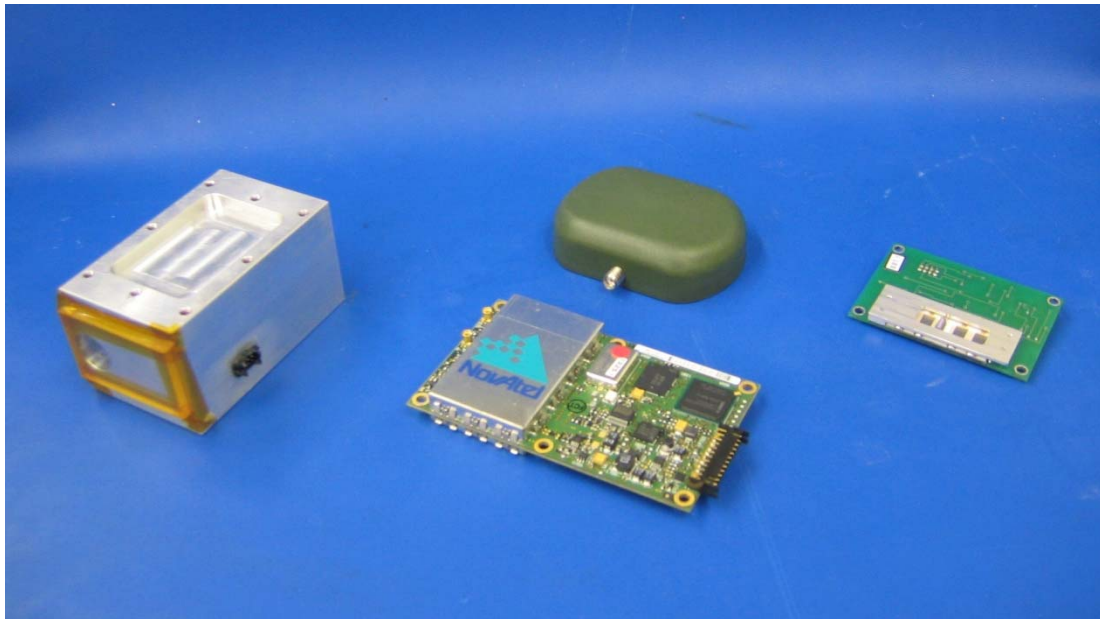
CMOS Imagers



S-Band Transmitter

Science Payloads

- Atmospheric Spectrometer: Green-house gasses
- GPS Occultation: Water vapour concentration (Troposphere) & Electron density (Ionosphere)
- Materials Science: Evaluate AO resistant coating

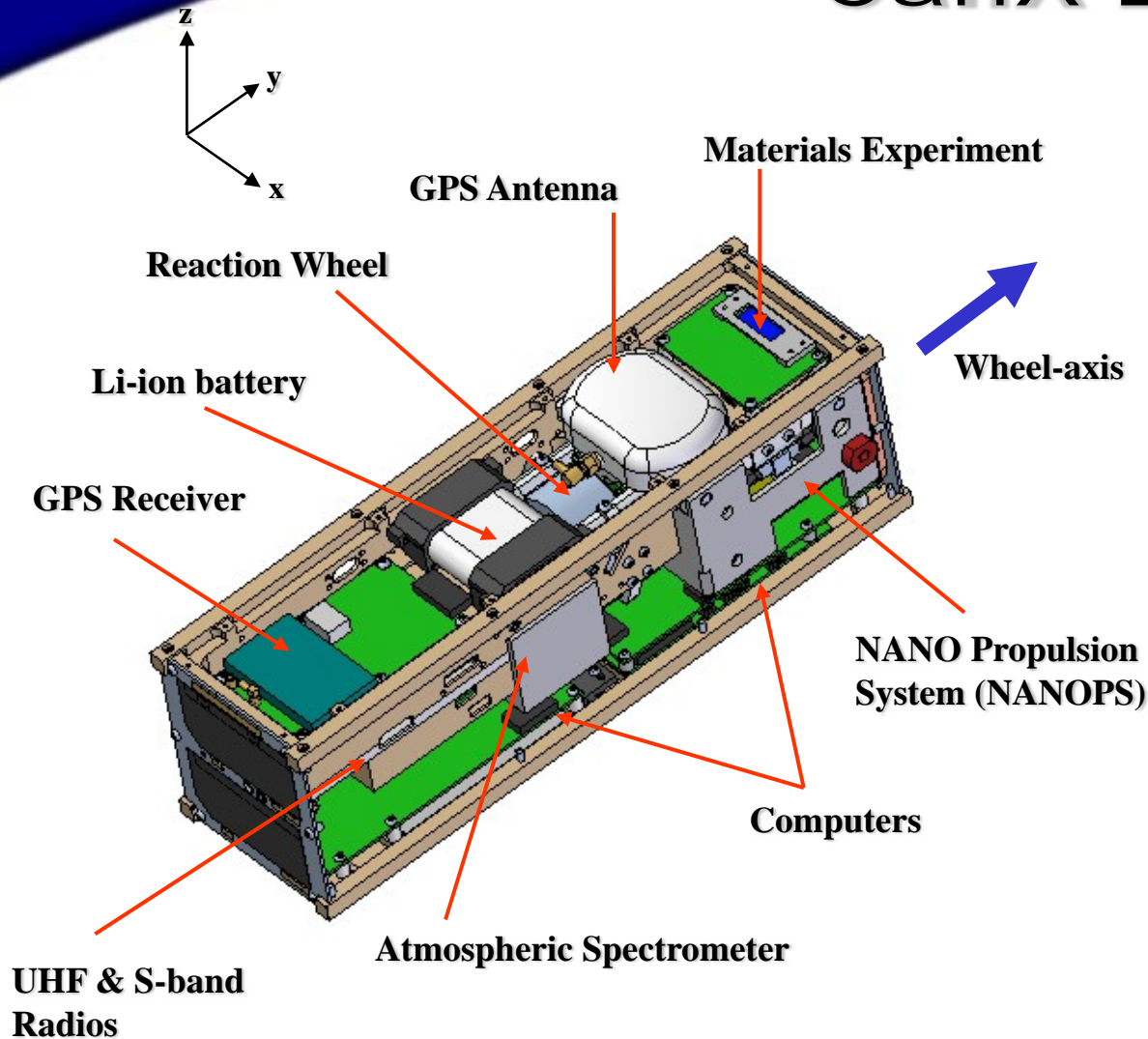


UNIVERSITY OF
CALGARY



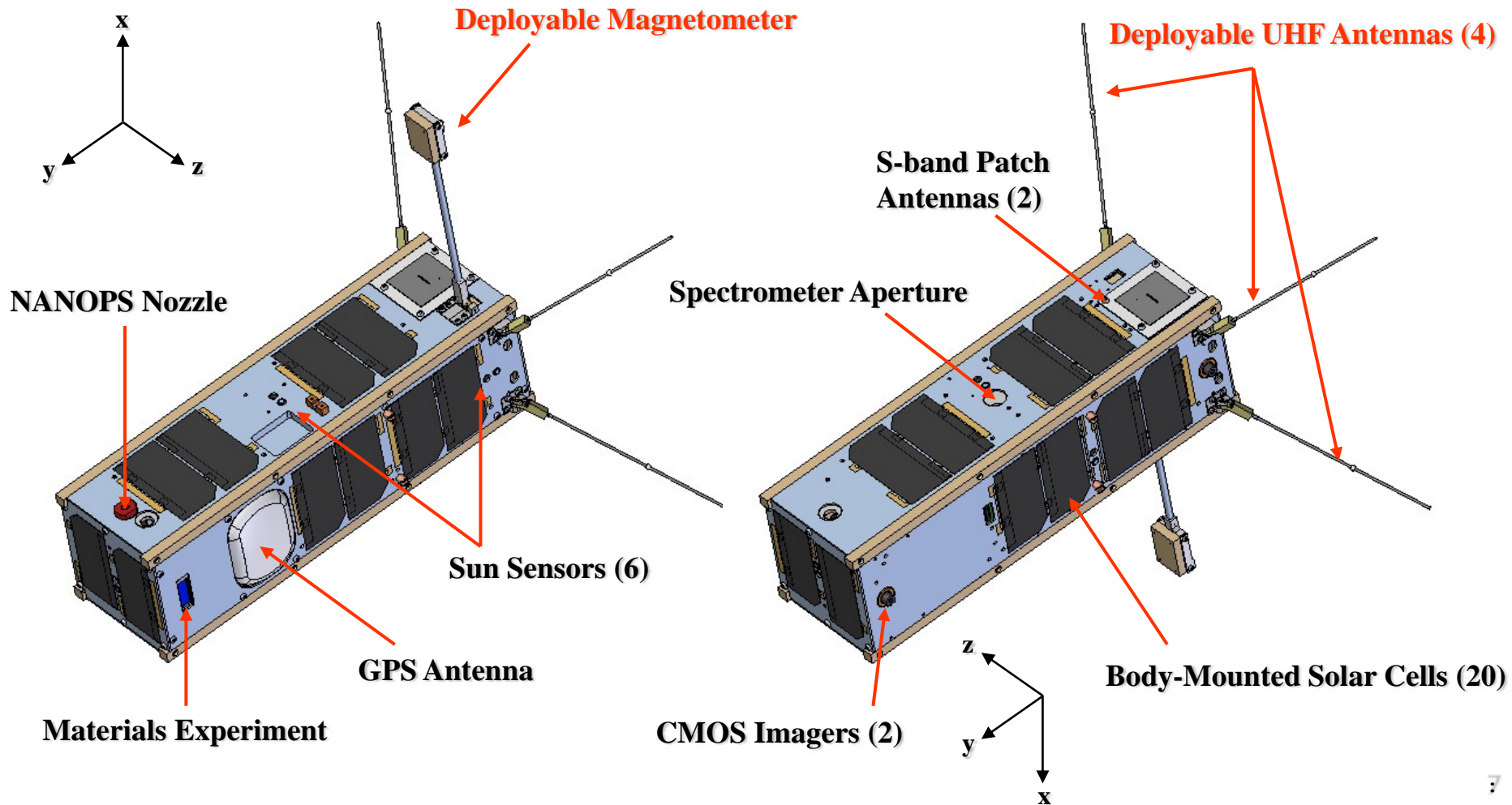
Carleton
UNIVERSITY

CanX-2 Bus



- **34 cm x 10 cm x 10 cm**
- **3.5 kg total mass**
- **1.25W time-average power consumption**
- **Tray-based design**

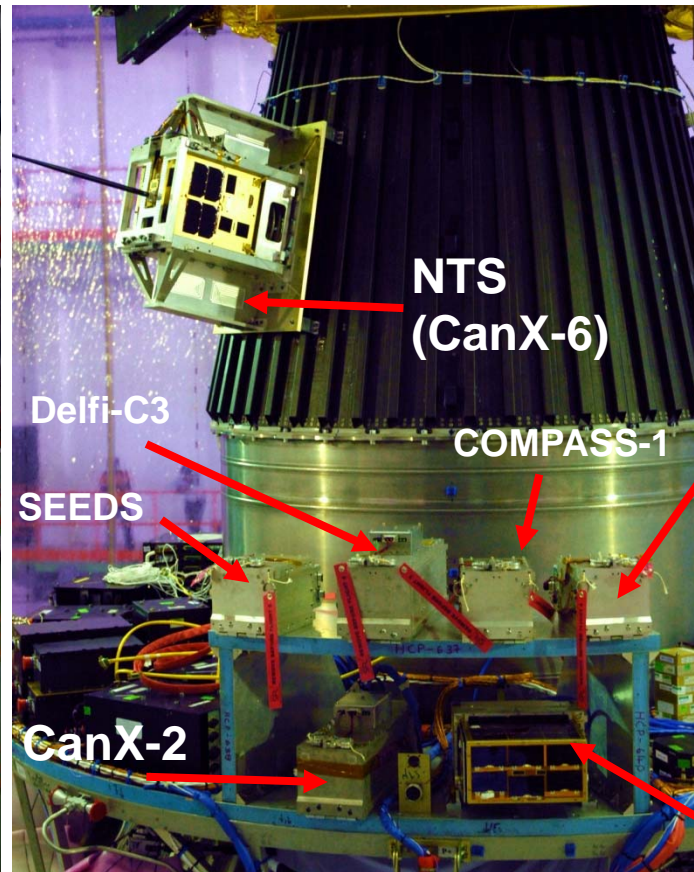
CanX-2 External layout



Launch Day



ISRO/Antrix PSLV C9
Vehicle Assembly Building
Sriharikota, India

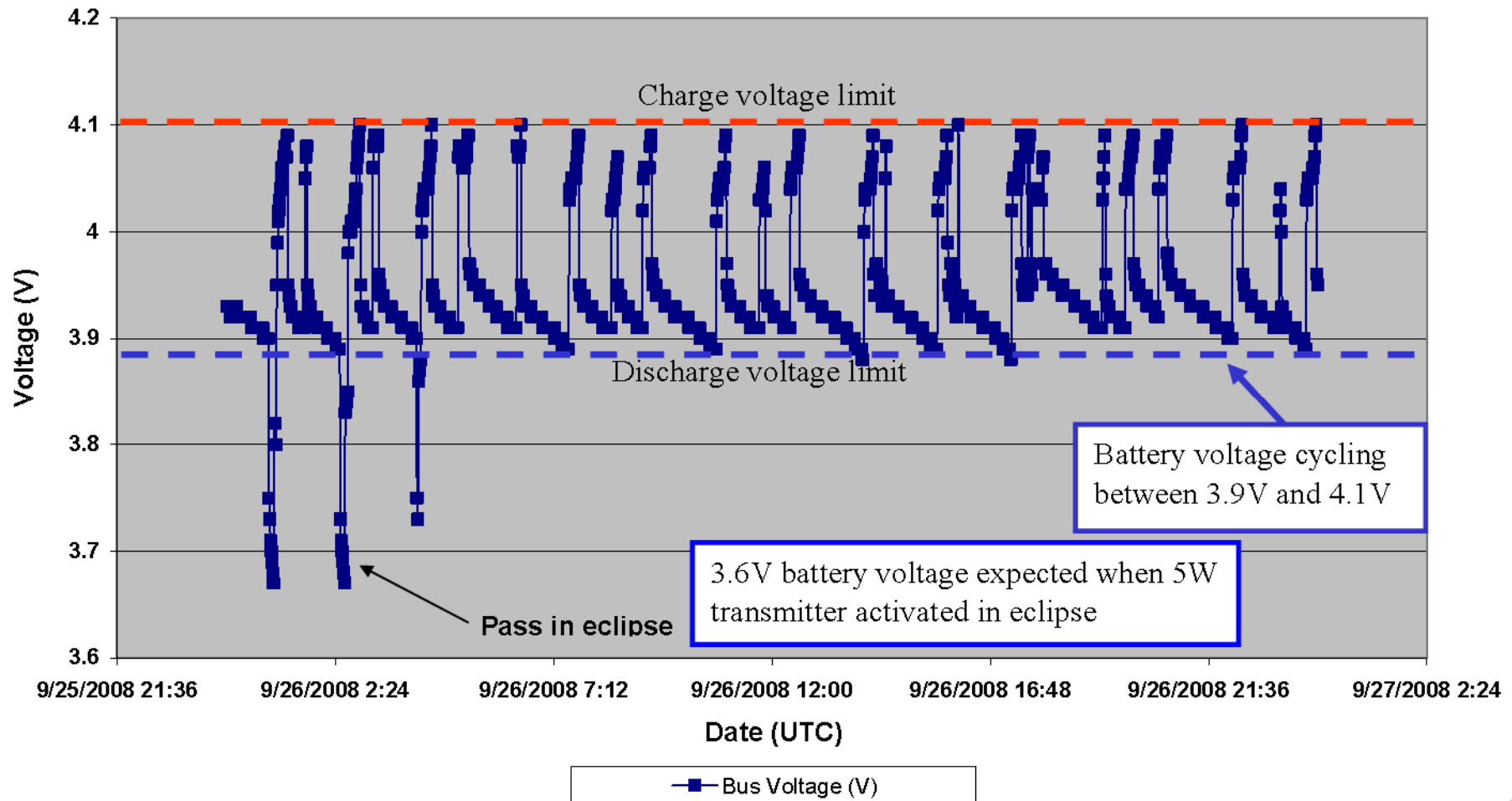


NLS-4 & NLS-5 Spacecraft & XPOD
deployment systems integrated with
PSLV upper stage



Launch: April 28th 2008
@ 03:53 UTC

Telemetry: Battery Voltage



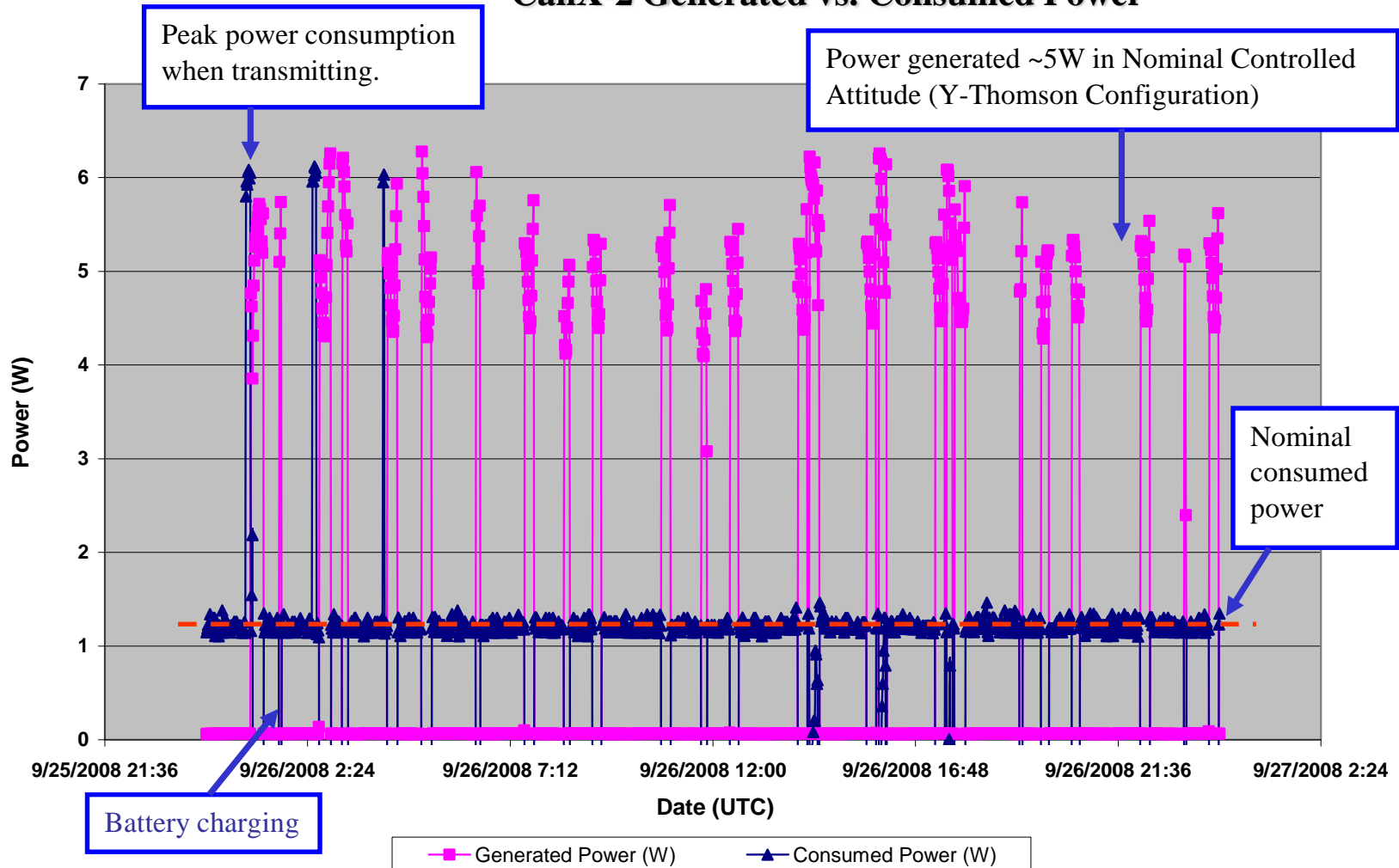
Telemetry: Power Generation

Nominal Controlled Attitude: Orbit Normal Alignment of Long Axis



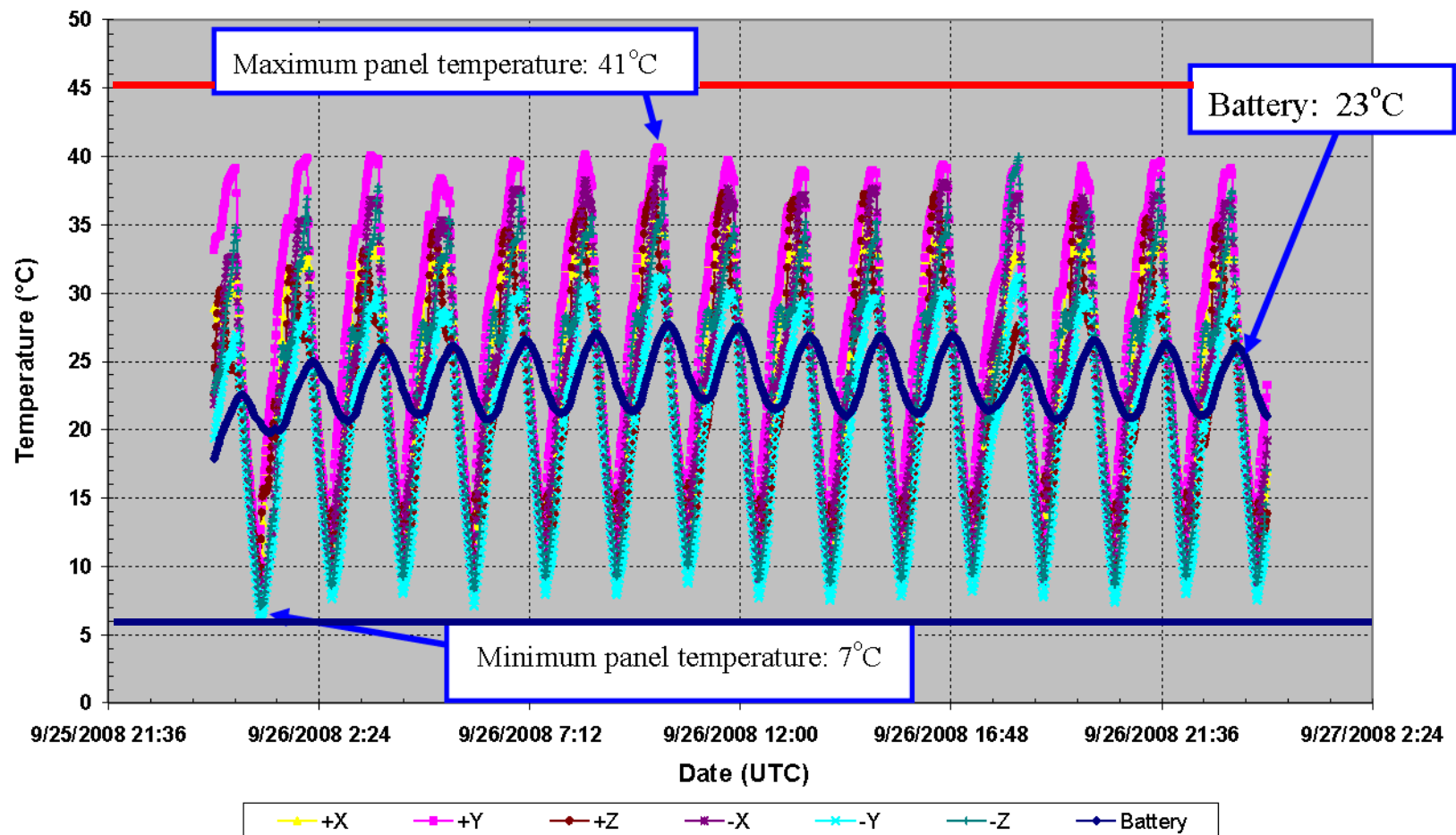
Telemetry: Power Generation

CanX-2 Generated vs. Consumed Power



Telemetry: Temperature

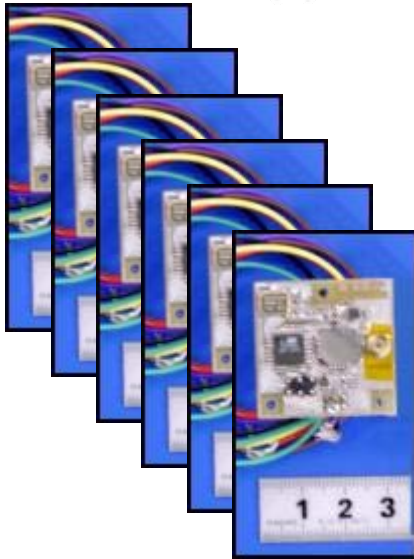
CanX-2 Structural Panel and Battery Temperature



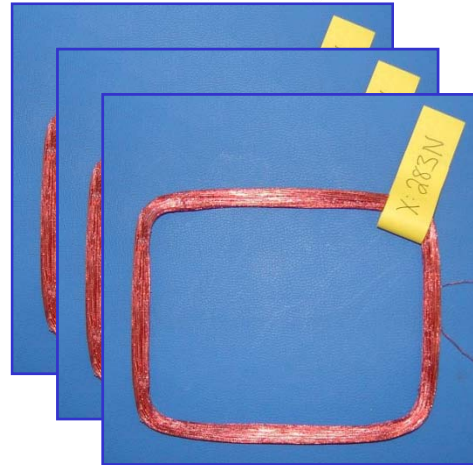
CanX-2 Primary Objective: Formation Flight Technology Demonstration

CanX-2 ADCS

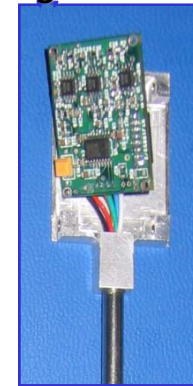
Sun Sensors (6)



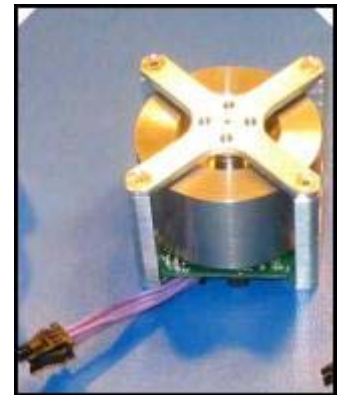
Magnetorquers (3)



Magnetometer



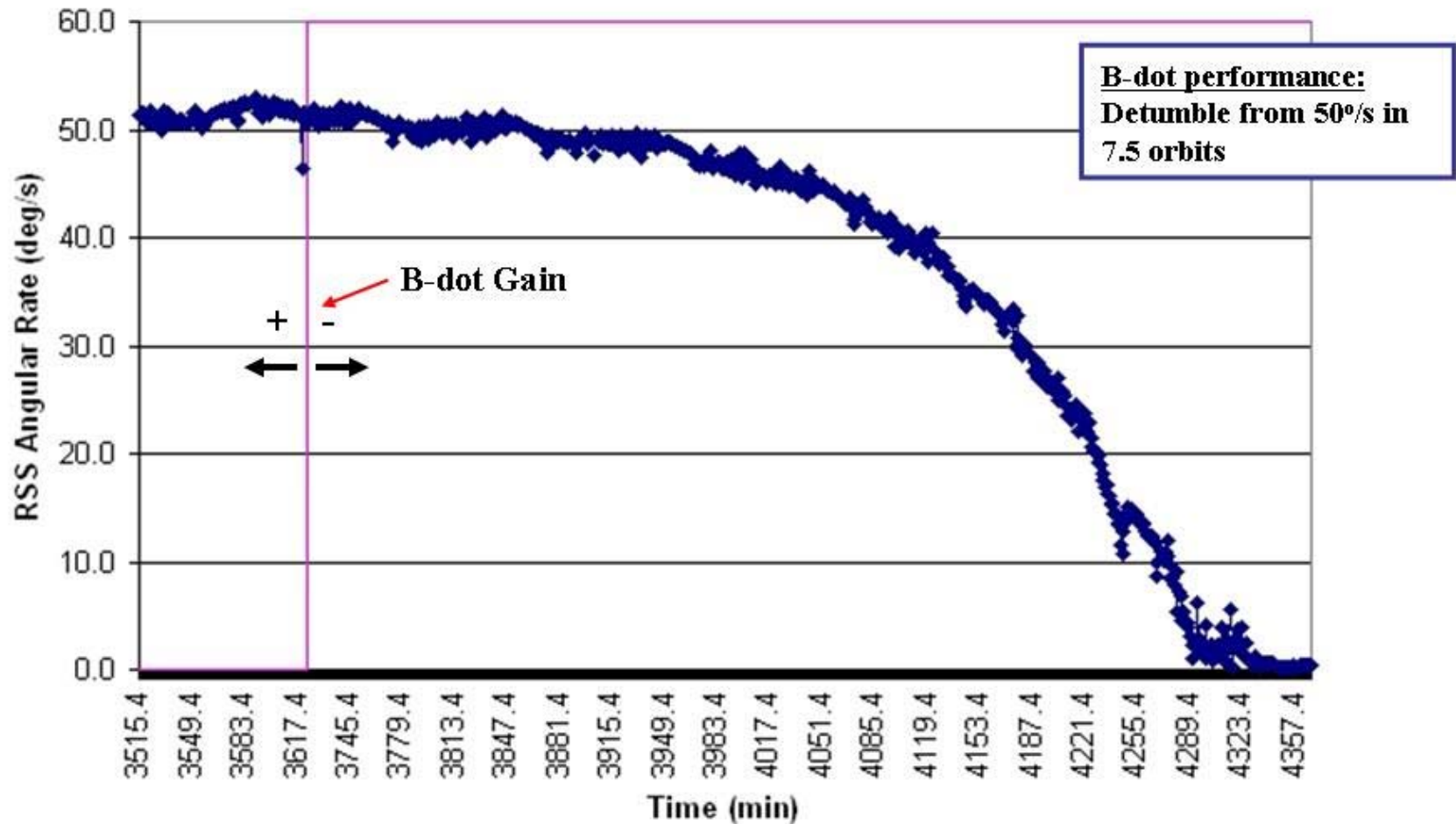
Reaction Wheel



Control Modes

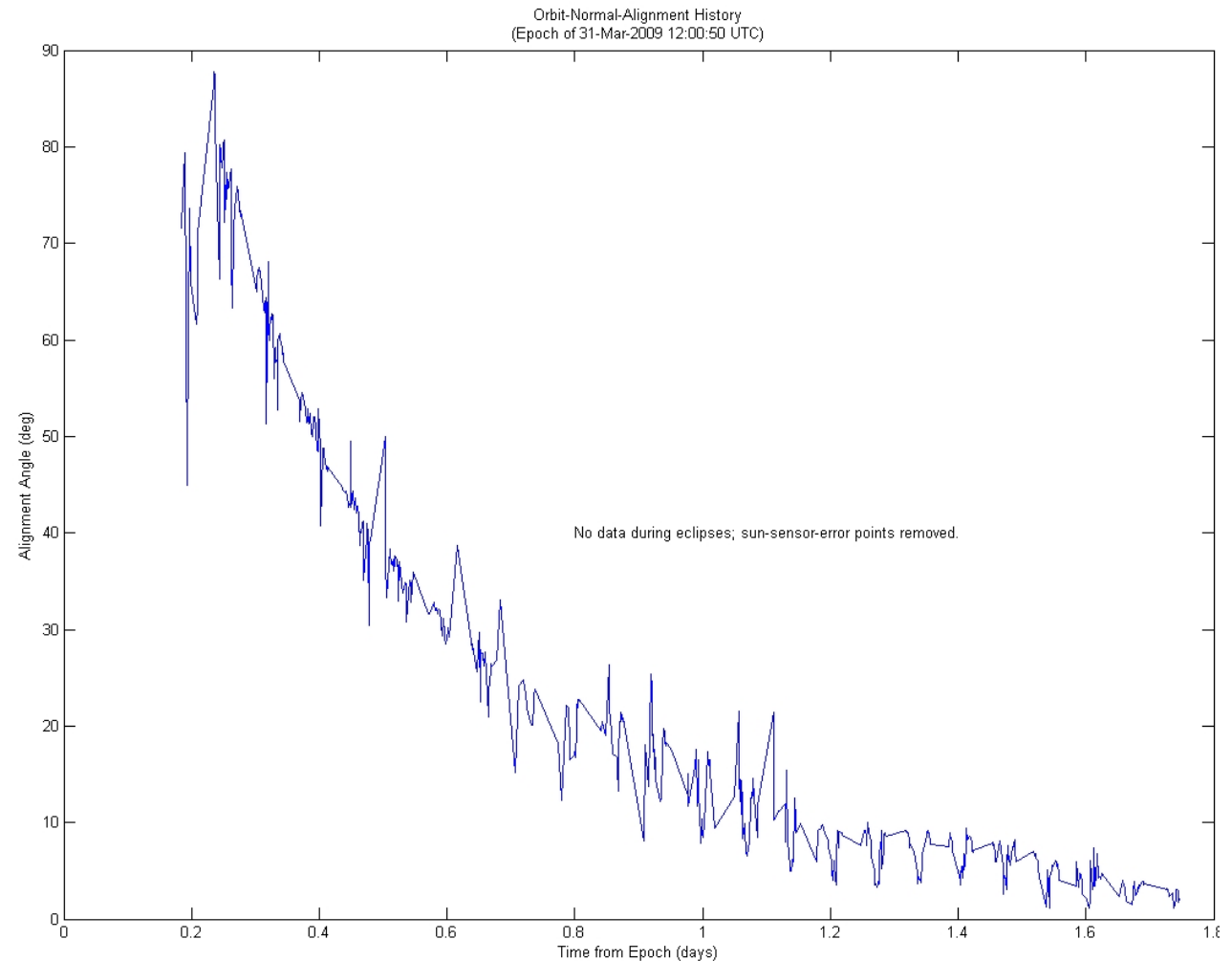
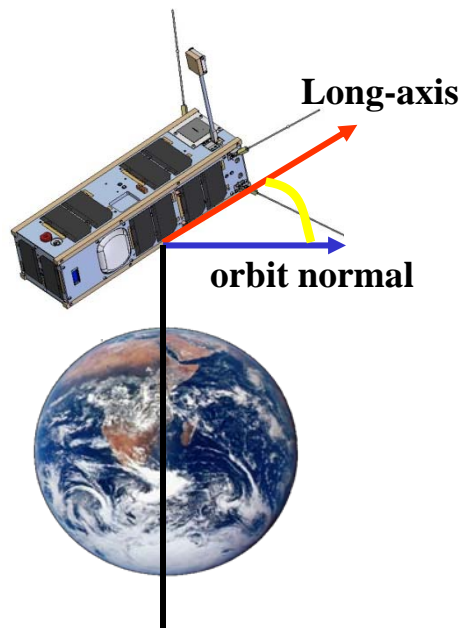
- B-dot (rate damping)
- Momentum Align (Y-thomson configuration orbit-normal alignment)
 - Wheel pitch (payload targeting about wheel axis)

B-Dot Control



CanX-2 b-dot rate damping controller reducing angular rates from 50°/s to 0°/s

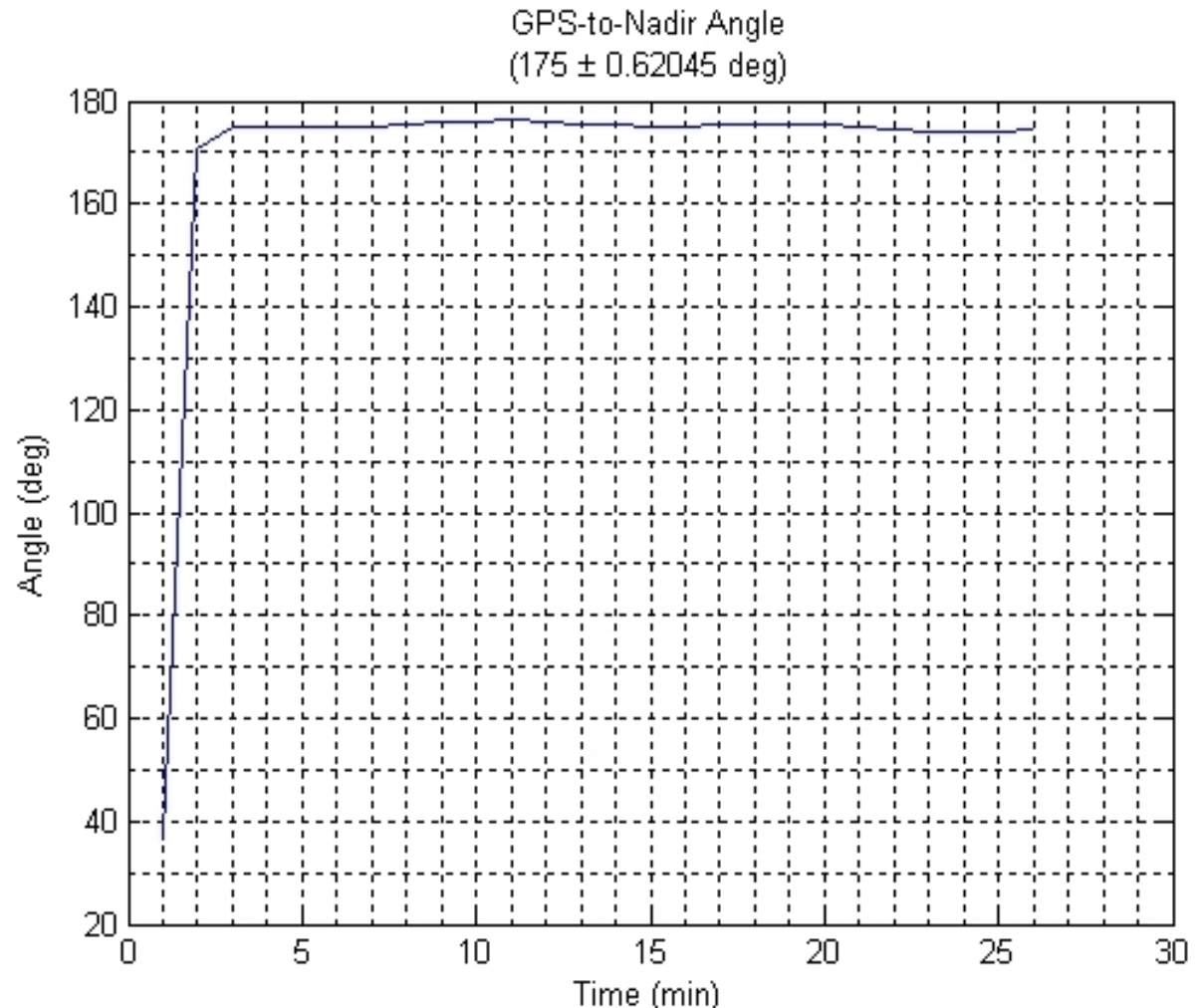
Momentum Align Control



Momentum align controller reducing angle between spacecraft Y-axis and orbit normal towards 0°

Wheel Pitch Control

- Aligns payloads to targets of interest in orbit frame
- 135° slew in 60s
- <5° pointing accuracy
- 1° stability over 25 minutes



Wheel pitch controller aligning GPS antenna towards zenith

CubeSat Compact Three-Axis Attitude Actuator and Sensor Pack with Sinclair Interplanetary

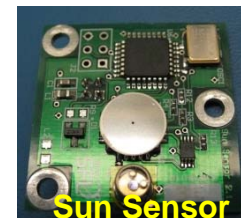
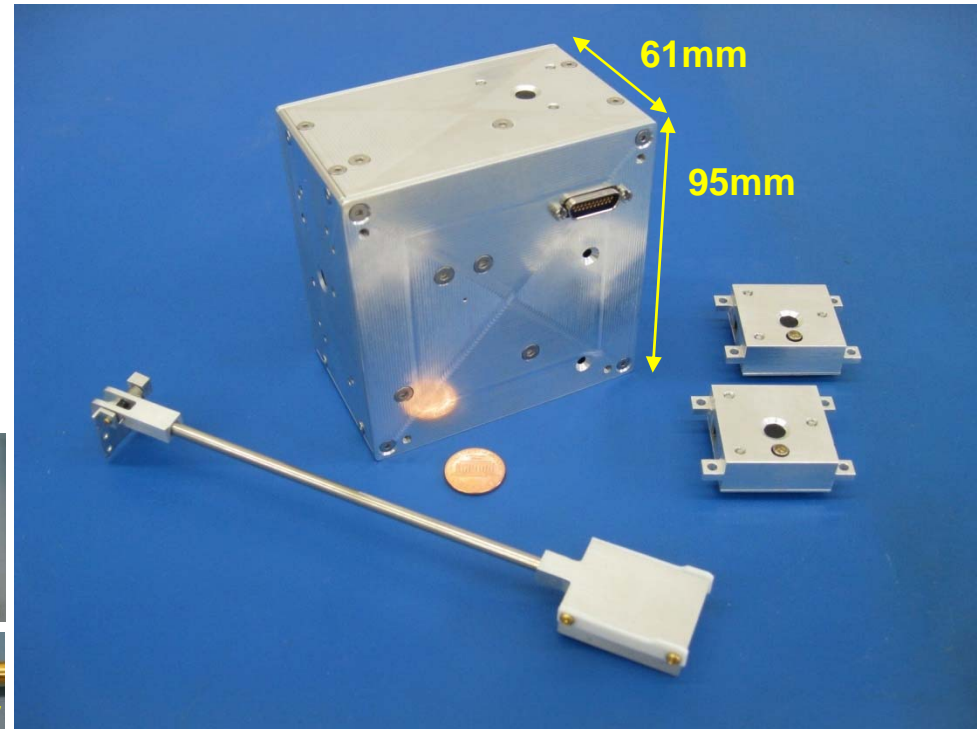
- Three-axis, achievable pointing accuracy of 1-2 deg RMS
- Package includes:
 - 3 reaction wheels (10mNms)
 - 3 magnetorquers
 - 6 sun sensors (up to two are external)
 - 1 magnetometer (external)
- Power: < 1 W typical
- Mass: <1 kg
- Dimensions: 95x95x61 mm
- Optional deployable magnetometer boom
- Easy-to-integrate box, compatible with Pumpkin CubeSat Kit
- CanX-2 heritage (1.3 years) and proven on-orbit performance



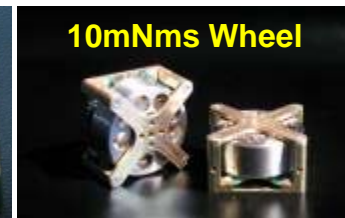
Magnetorquer



Magnetometer



Sun Sensor

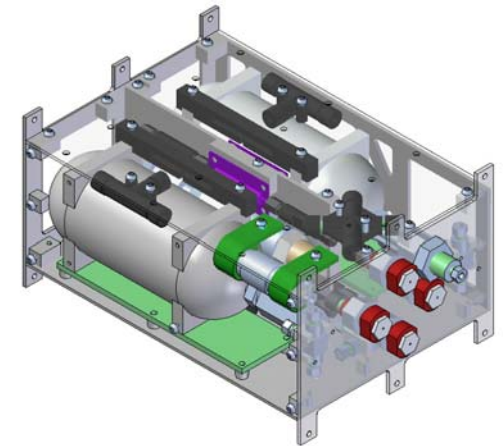


10mNms Wheel

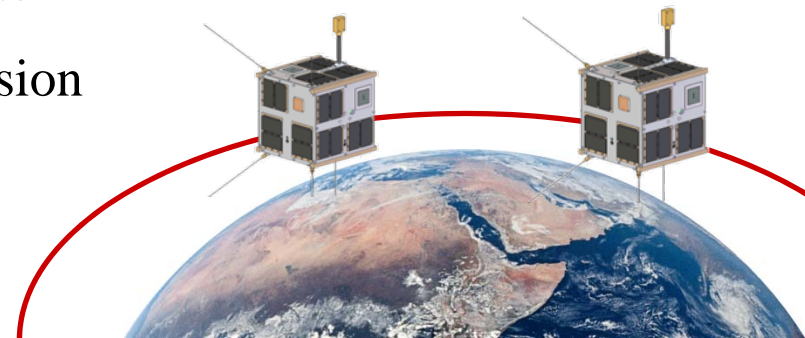
NANO Propulsion System

CanX-4 & -5 Propulsion System: CNAPS

- NANOPS Basics:
 - Liquid fuel, cold-gas propulsion system
 - Sulfur Hexafluoride propellant
 - Built entirely using commercial technologies
- Purpose:
 - Qualify proof-of-concept propulsion system
 - SFL's CanX-4 & -5 formation flight mission will use a scaled-up propulsion system

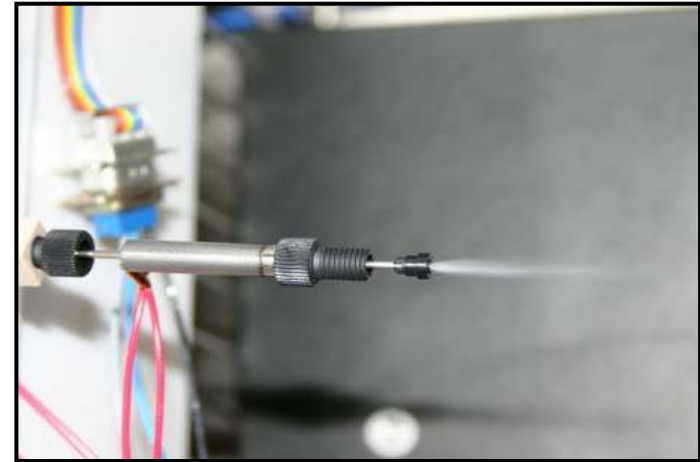


CanX-4 & -5



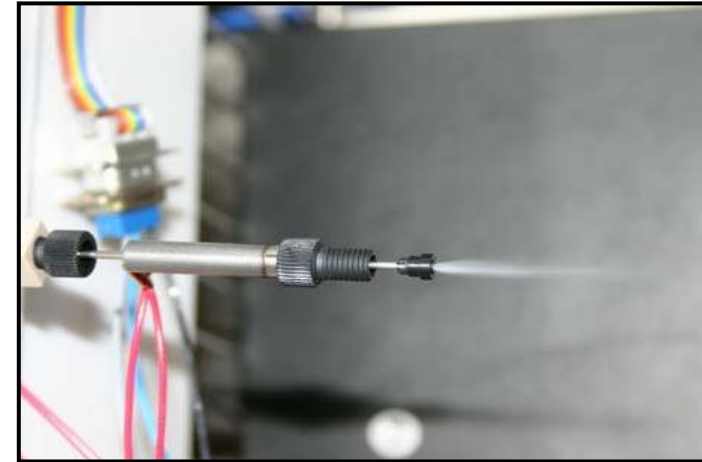
NANOPS Orbit Results

- **Fuel Leakage:**
 - Negligible fuel loss
 - Consistent with ground-based testing



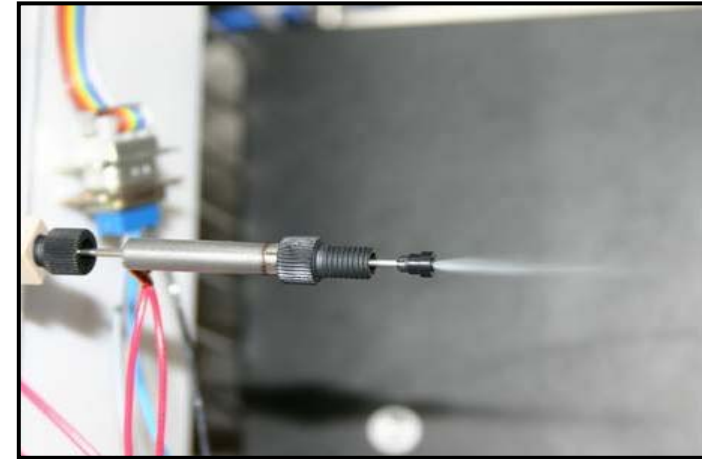
NANOPS Test Results

- Fuel Leakage: Negligable
- **ISP**
 - Minimum: 44s
 - Average: 46s
 - SF₆ Theoretical Maximum: 45s-50s



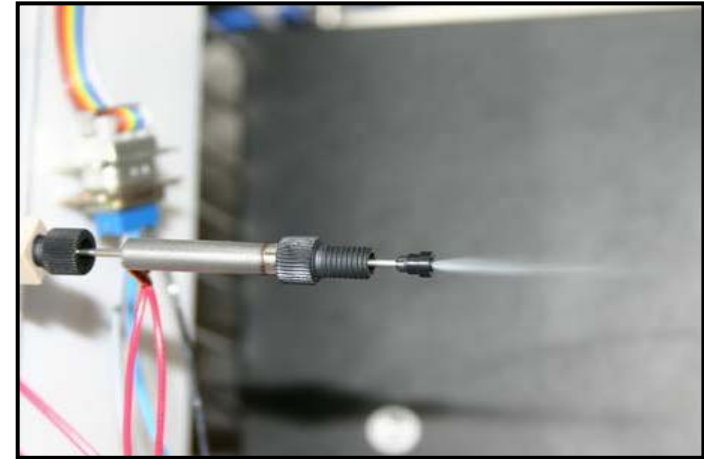
NANOPS Test Results

- Fuel Leakage: Negligable
- ISP: ~46s
- **Minimum Impulse Bit:**
 - 0.07 mNs (@ 75psi)
 - 0.15 mNs (@ 255psi)
 - 0.13 mNs average



NANOPS Test Results

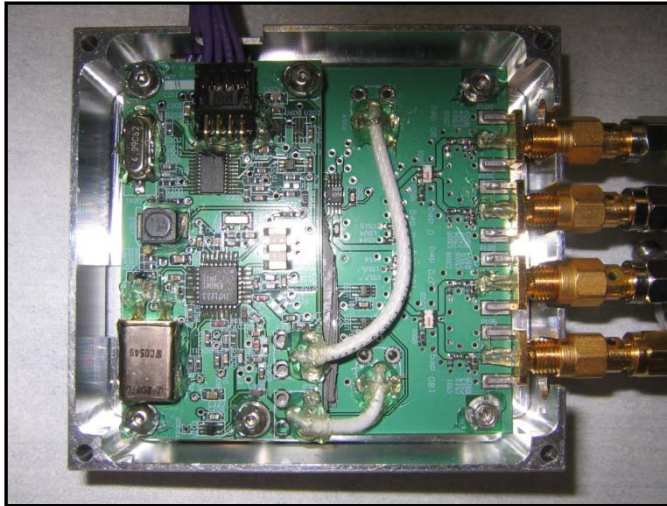
- Fuel Leakage: Negligable
- ISP: ~46s
- Minimum Impulse Bit: ~0.13 mNs



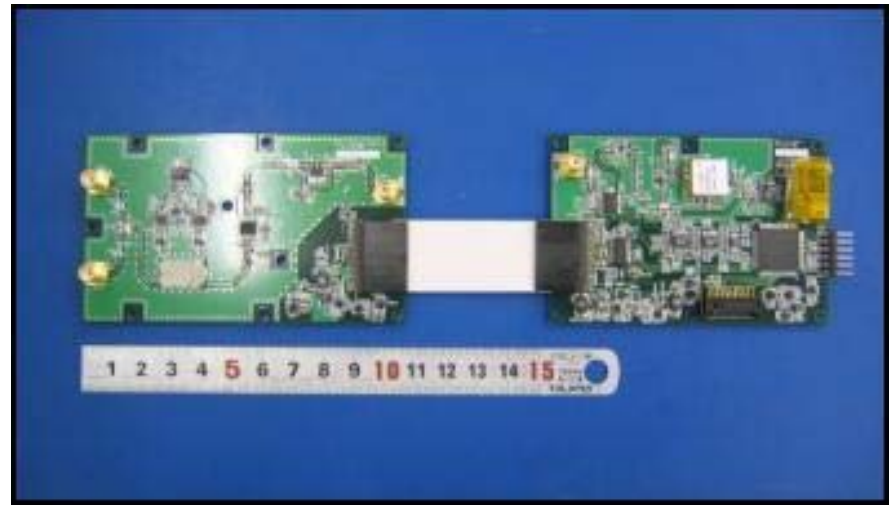
Upcoming NANOPS testing

- Long-duration thrust
 - Determine Impulse & thrust-level at various pressures

Radios



UHF Transceiver



S-Band Transmitter

- Radios functioning nominally
- Data rates up to 1mbps demonstrated on orbit
- Over 400MB of payload & telemetry data downloaded

CanX-2 Secondary Objective: Scientific Experimentation

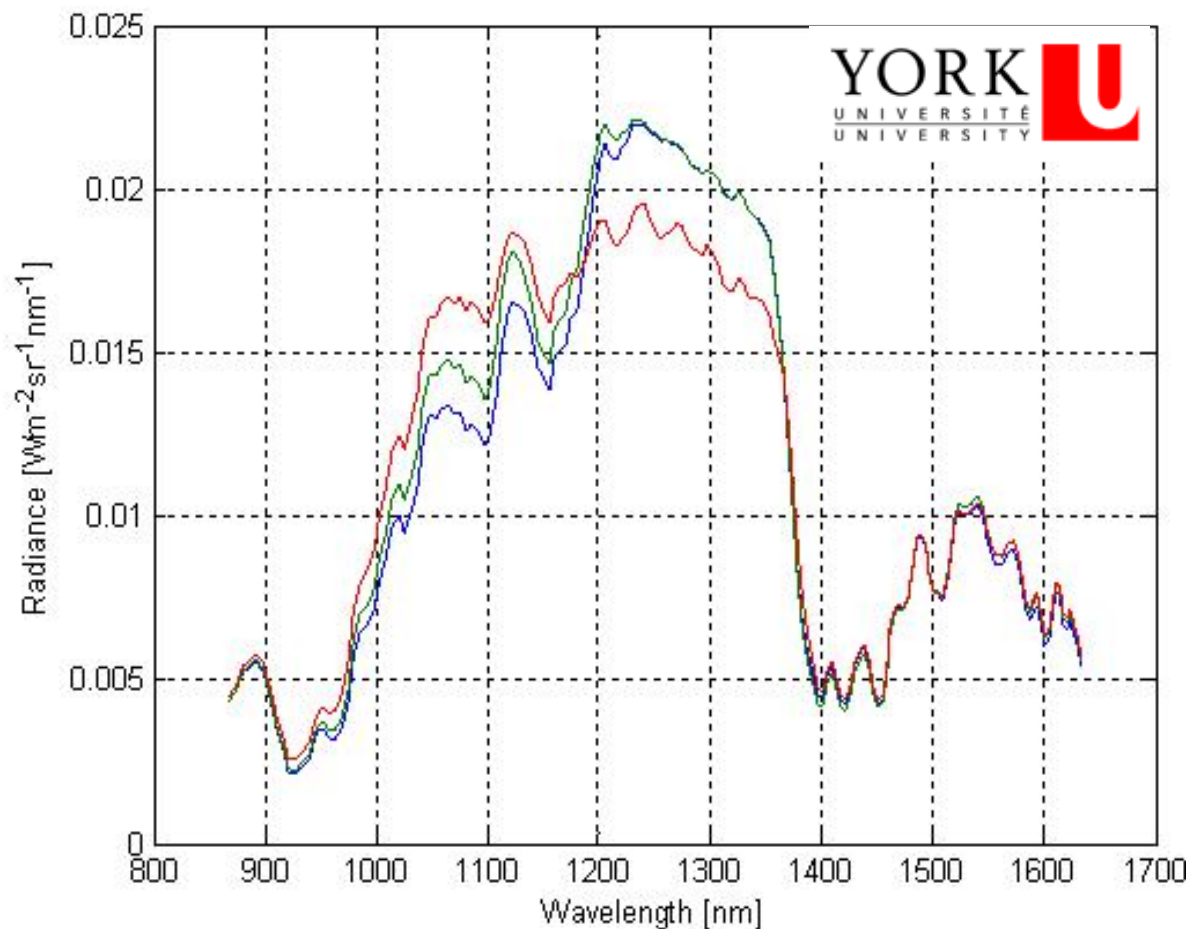
Spectrometer



**Argus Spectrometer 1000 provided
by York University, Toronto**

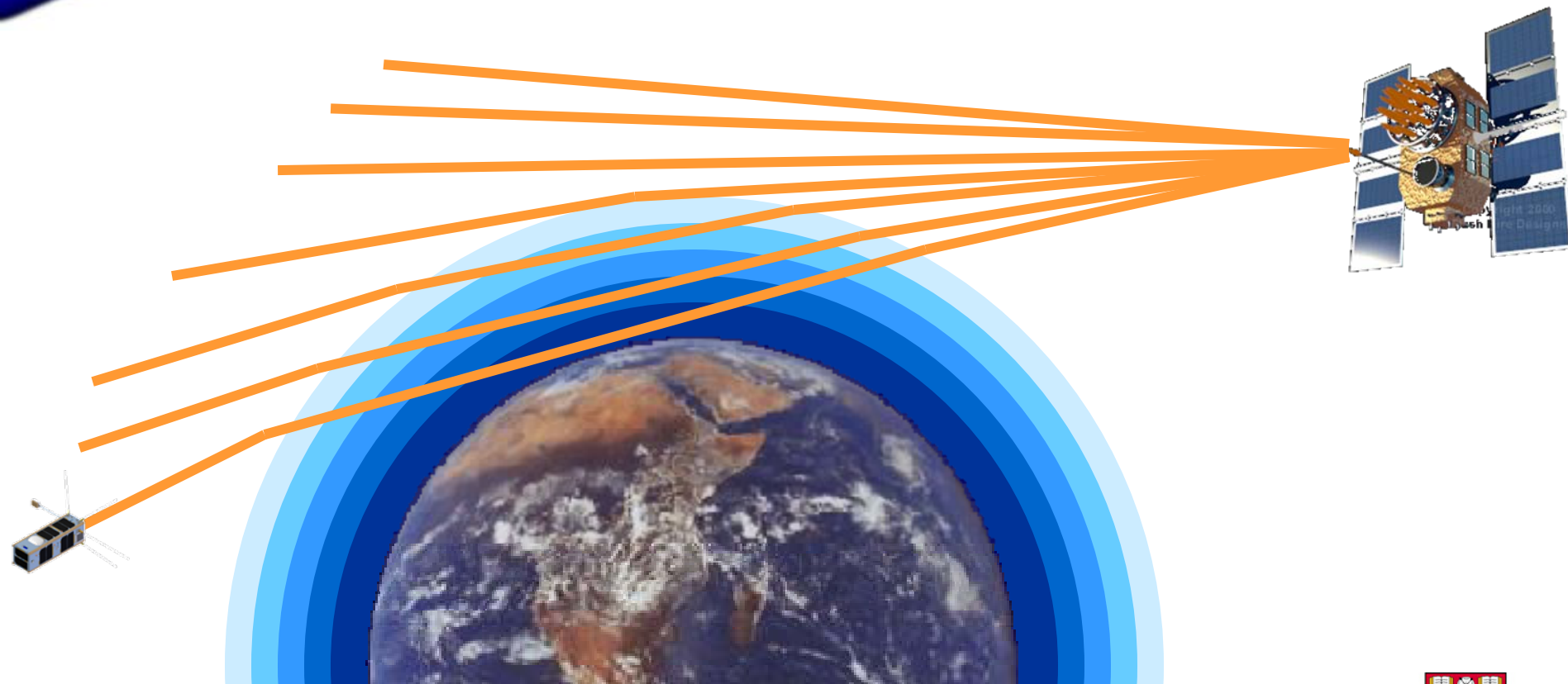


**STK animation of CanX-2
spectrometer observation**



**Spectra of greenhouse gases taken over Ontario,
Canada by CanX-2/Argus 1000 spectrometer**

GPS Occultation

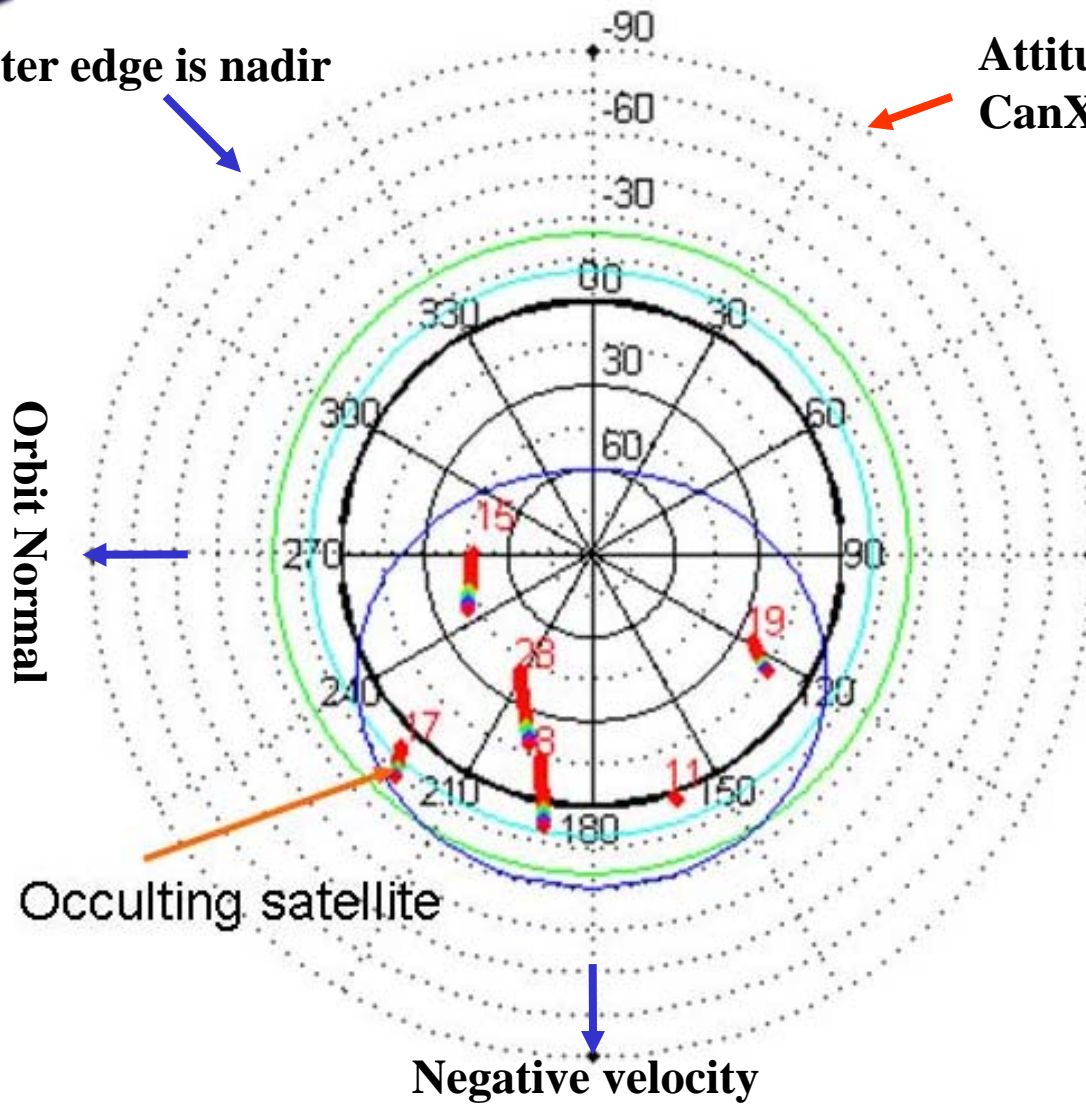


- Mapping of watervapour (troposphere) and electron density (ionosphere) can be generated through measurement occulting L2 GPS signals.
- Widespread weather applications & improve GPS estimate accuracy

GPS Occultation

Outer edge is nadir

Attitude plot of successful
CanX-2 occultation trial



- Require 5 tracked GPS satellites min. 4 above atmosphere, 1 occulting in atmosphere.
- Occulting spacecraft near center of antenna FOV to maximize weak L2 signal.
- Record occulting data at 50Hz

- Earth
- Atmosphere boundary
- GPS antenna FOV

Conclusion

- First fifteen months in orbit is a success!



Conclusion

- First fifteen months in orbit are a success!
- Many achievements have been accomplished during 1st year in orbit

Rapid commissioning of spacecraft hardware & software



Payload operations commenced mere days after launch



Characterization of NANOPS, orbit results matching expectations



Accurate attitude estimation and pointing demonstrated



Solid performance of attitude sensors and miniature wheel



Unprecedented radio performance for operational nanosatellite



Proven accuracy of power & thermal models

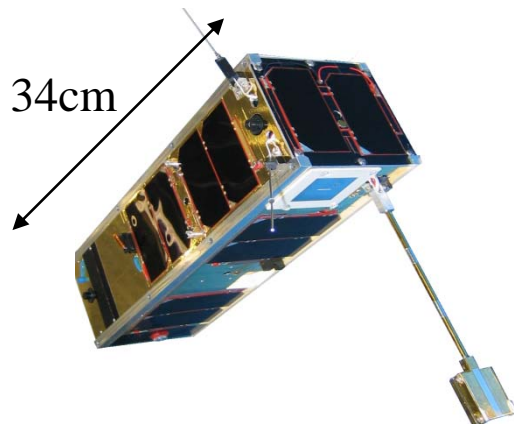


Hundreds of successful scientific experiments executed on orbit



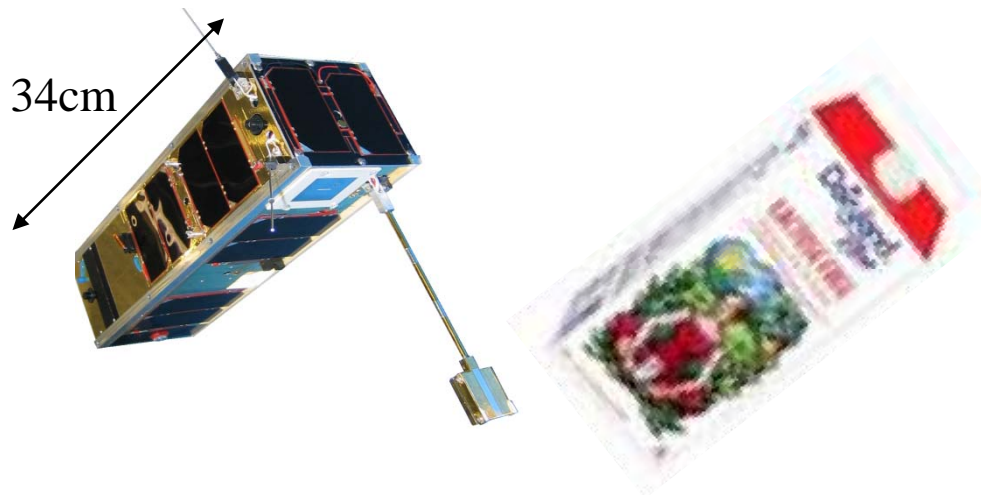
Conclusion

- First fifteen months in orbit are a success!
- Many achievements have been accomplished during 1st year in orbit
- CanX-2 is a clear-cut example of what a nanosatellite on a limited budget is capable of accomplishing.



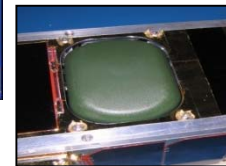
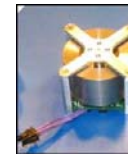
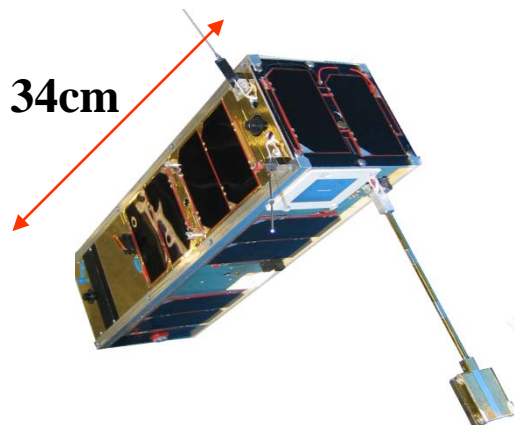
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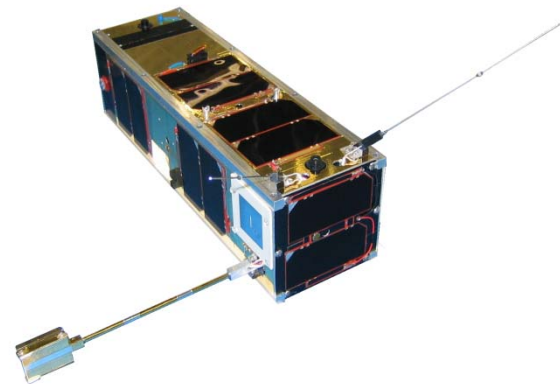
Conclusion

- First fifteen months in orbit are a success!
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Conclusion

- First fifteen months in orbit are a success!
- Many achievements have been accomplished during 1st year in orbit
- CanX-2 is a clear-cut example of what a nanosatellite on a limited budget is capable of accomplishing.
- CanX-2: A trail blazing mission; demonstrate critical technologies



Conclusion

- First fifteen months in orbit are a success!
- Many achievements have been accomplished during 1st year in orbit
- CanX-2 is a clear-cut example of what a nanosatellite on a limited budget is capable of accomplishing.
- CanX-2: A trail blazing, technology demonstration mission for SFL
- **Generic Nanosatellite Bus (GNB):** An even *more* capable platform. Built upon heritage & experience of CanX-2

First GNB Launch: 2009

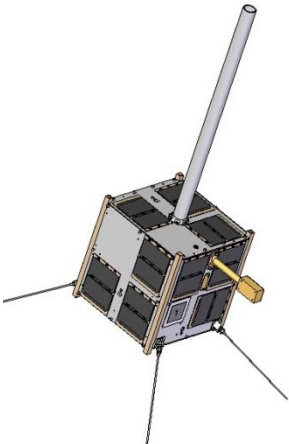
Please visit our booth for more info!

CanX Missions

Generic Nanosatellite Bus (GNB)

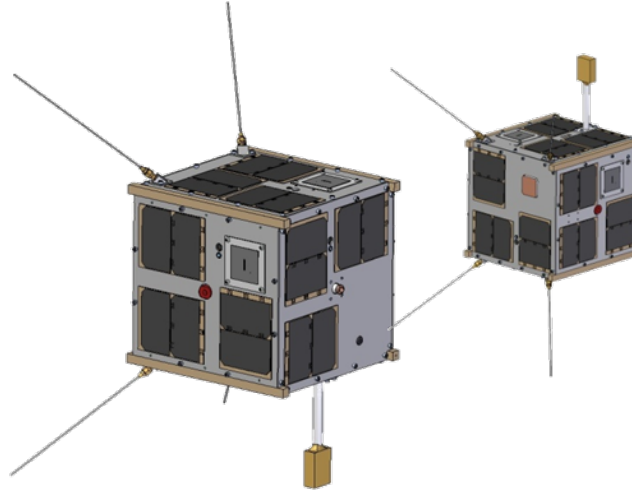
AISSat-1

AIS-sensor payload (Norway)



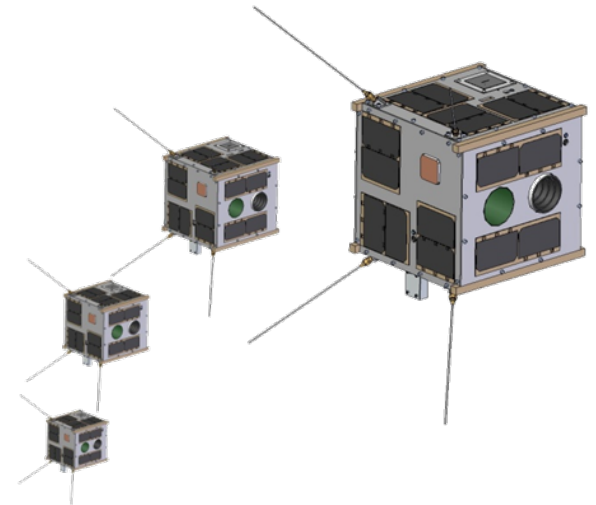
CanX-4/-5

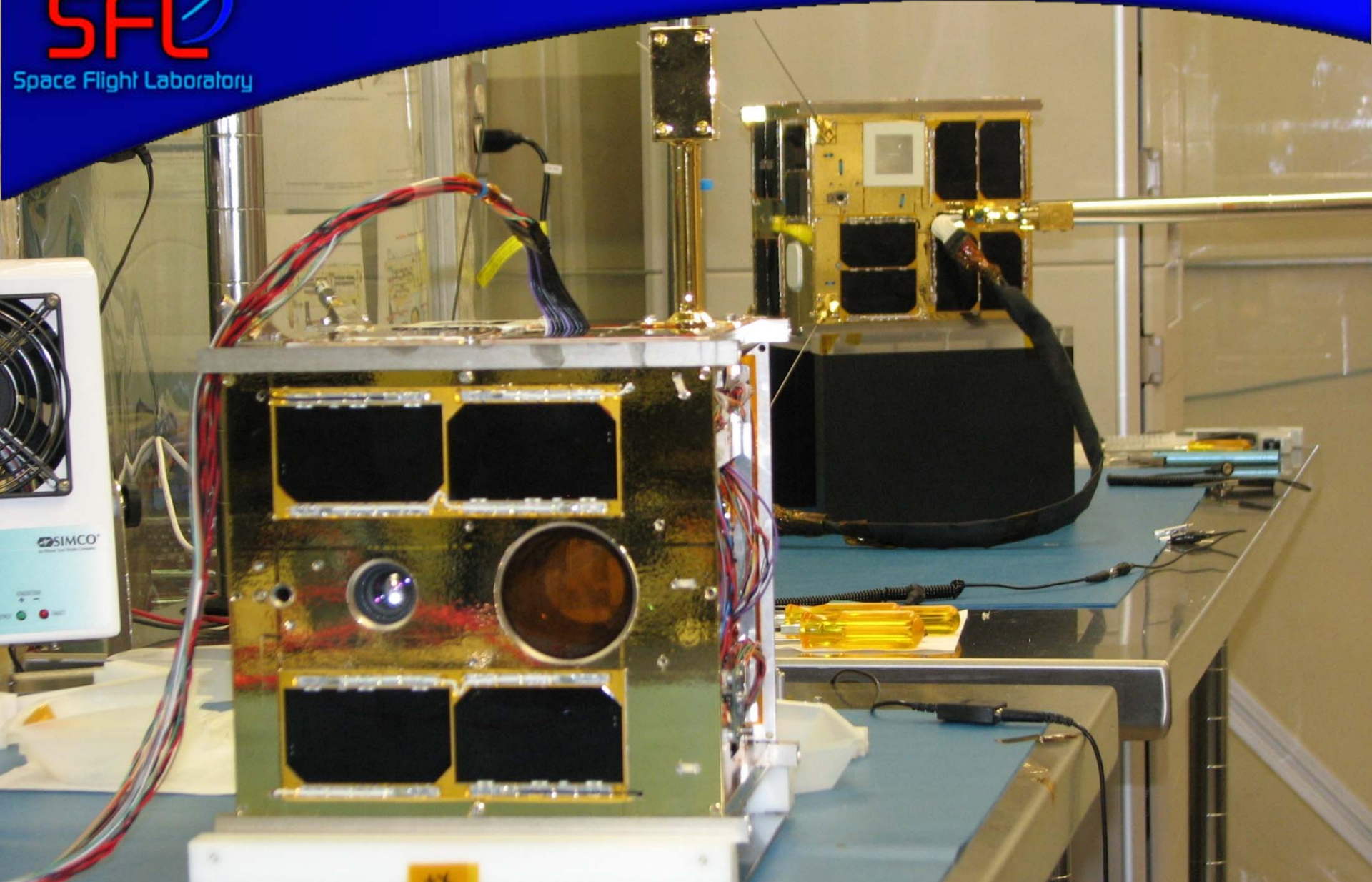
Formation-Flight Demonstration



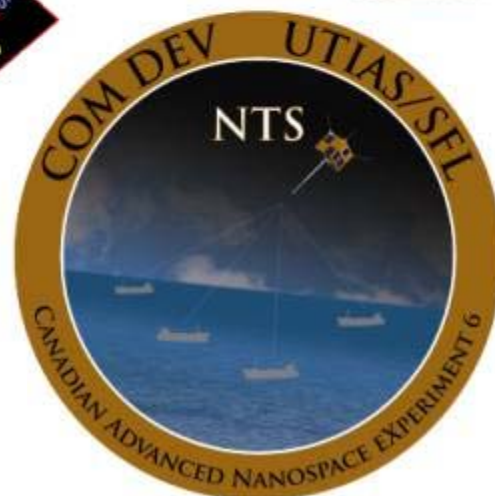
CanX-3

Stellar Photometry Constellation





UniBRITE and AISSat-1 – SFL Clean Room

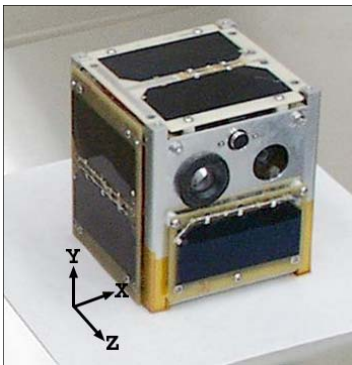


www.utias-sfl.net

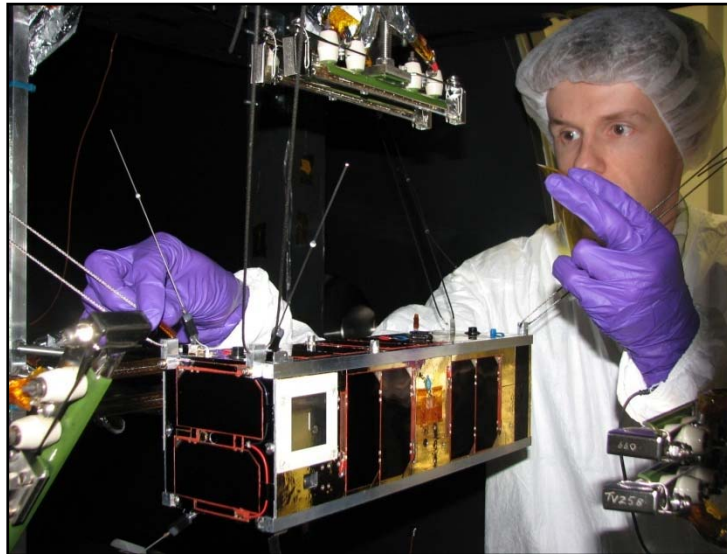
CanX Missions

- Technology demonstrator
- 10x10x10cm; 1kg
- Launched in 2003

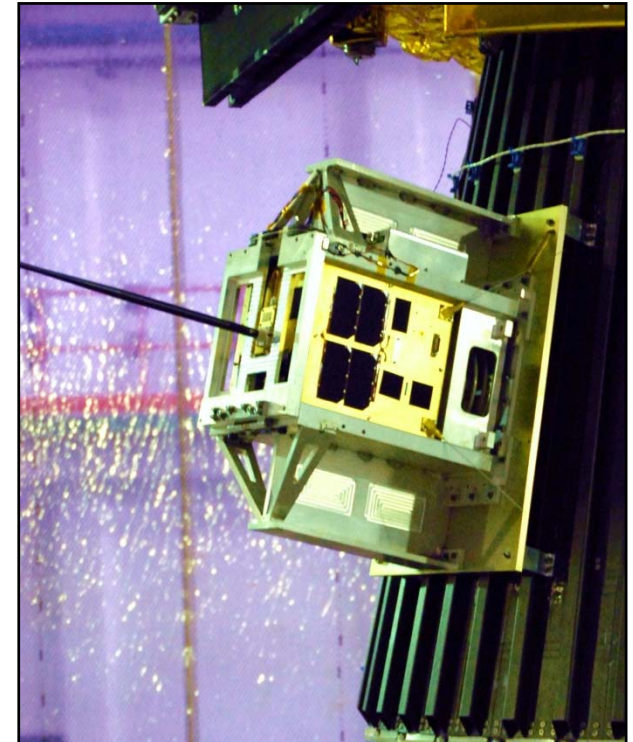
CanX-1



CanX-2



NTS (CanX-6)



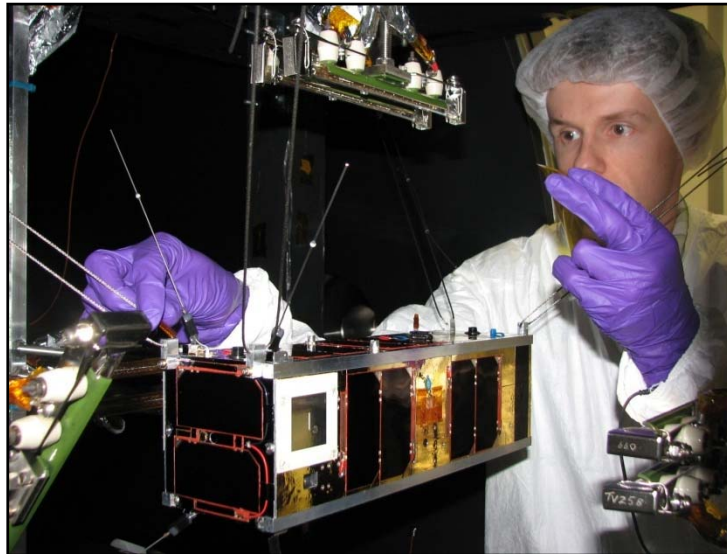
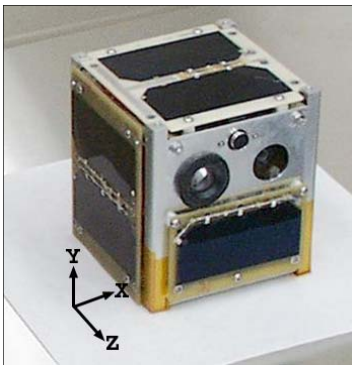
CanX Missions

- Technology demonstrator
- Science platform
- 34x10x10cm; 3.5kg

CanX-2

NTS (CanX-6)

CanX-1

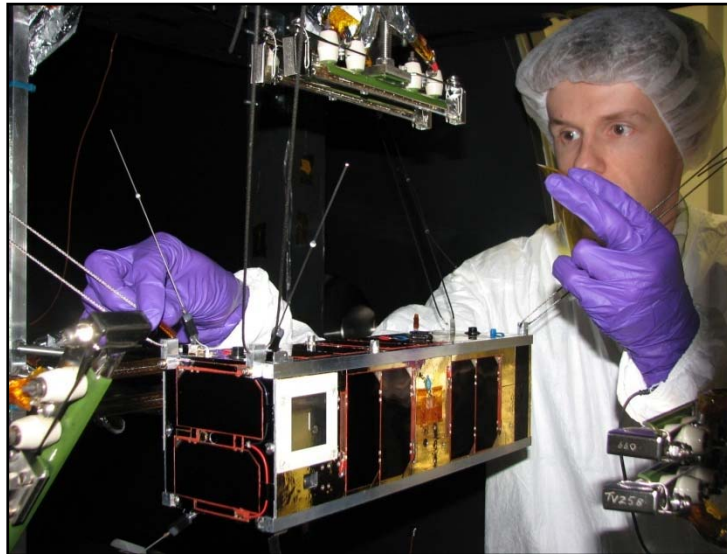
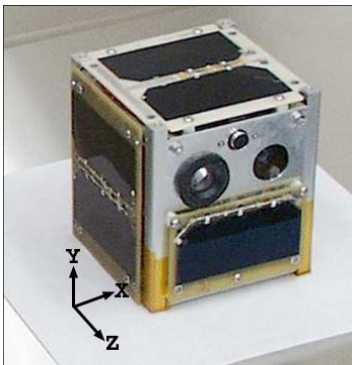


CanX Missions

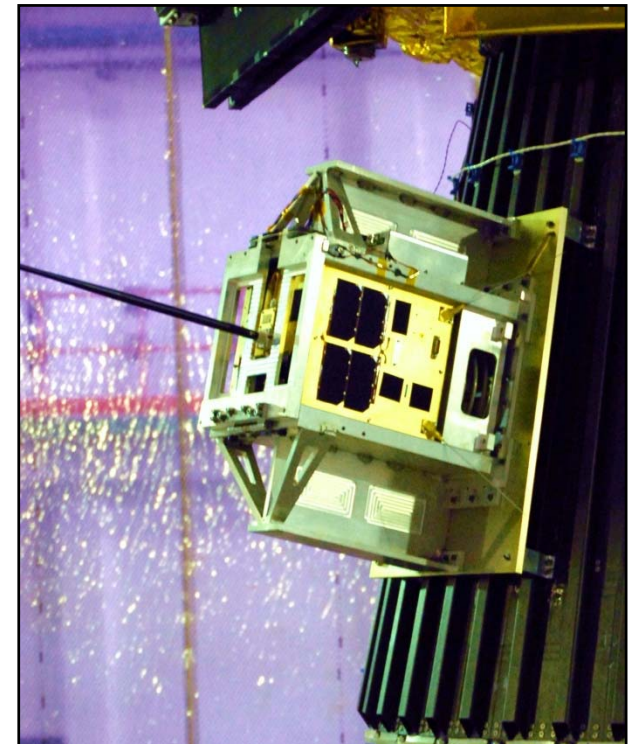
- Space-based AIS-sensor (Com Dev Intl.)
- 7 mo. from conception to launch
- 20x20x20cm; 6.5kg

CanX-2

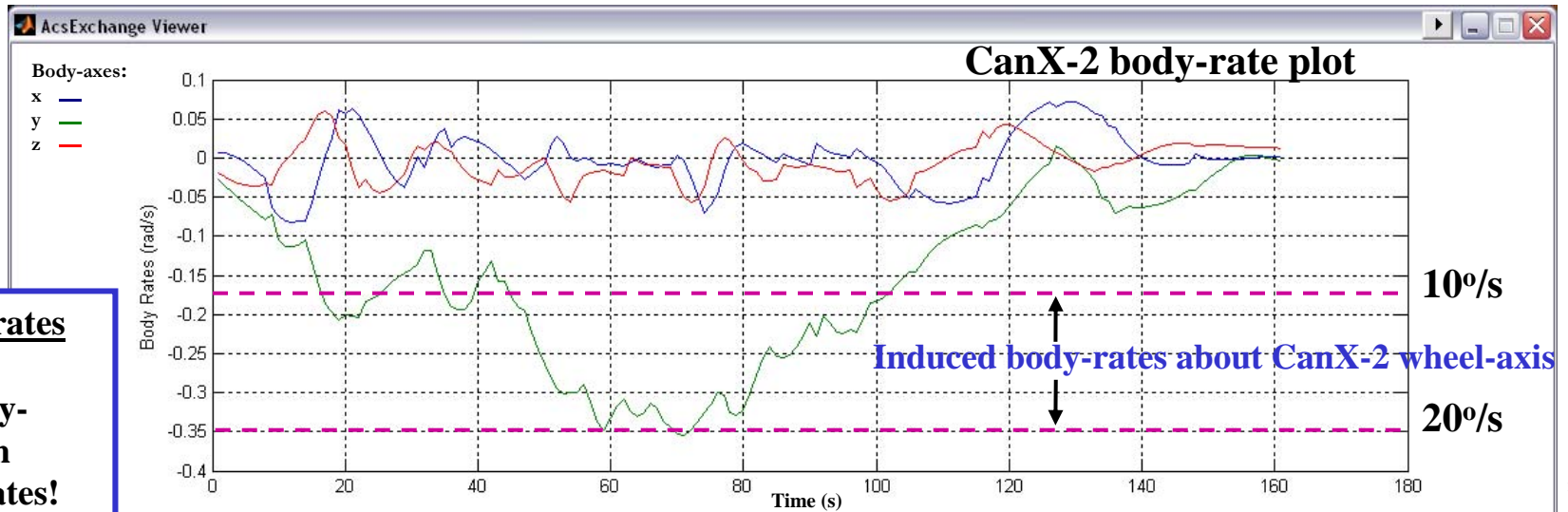
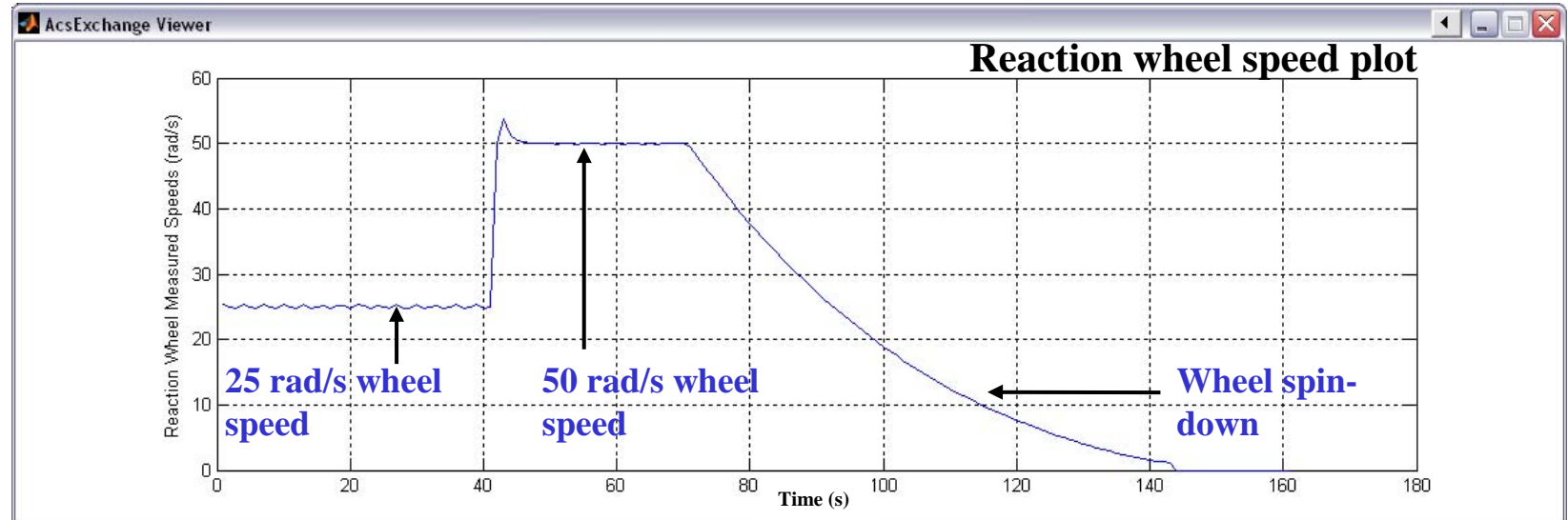
CanX-1



NTS (CanX-6)



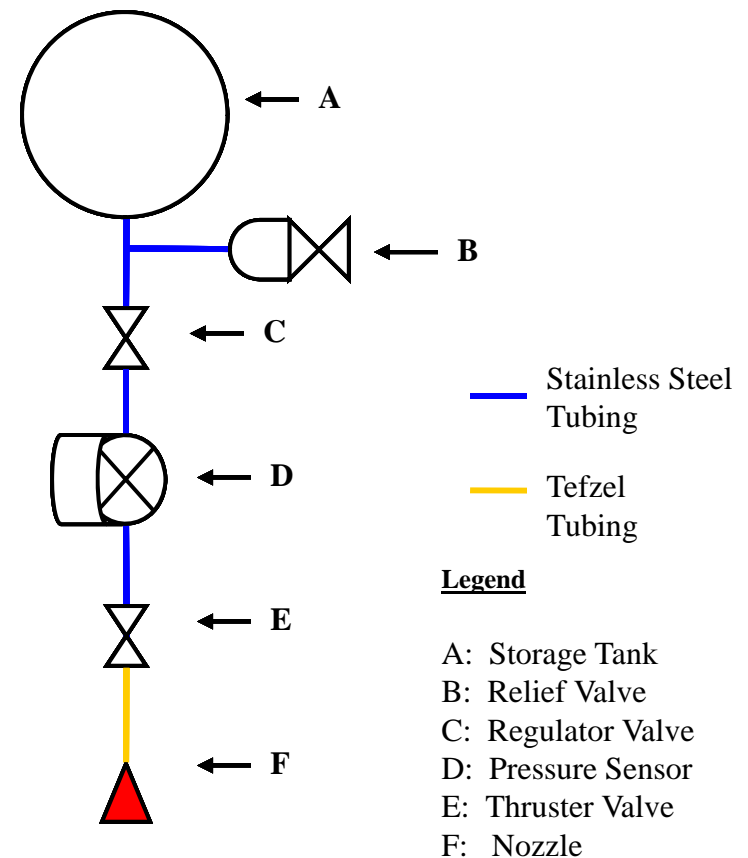
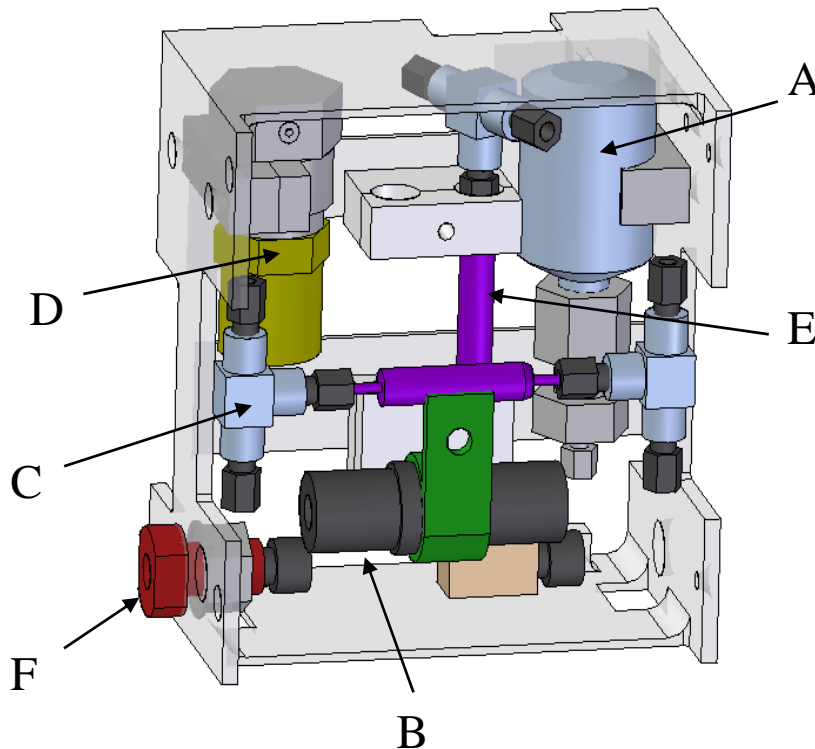
Wheel Spin-up



**Wheel operates nominally:
Actual body-rates match expected rates!**

NANOPS Propulsion

NANOPS Schematic



NANOPS Test Results

- Fuel Leakage: Negligable
- ISP: ~46s
- Minimum Impulse Bit: ~0.13 mNs
- Thrust valve on-time (testing to date):
 - Min: 1ms
 - Max: 500ms

NANOPS Test Results

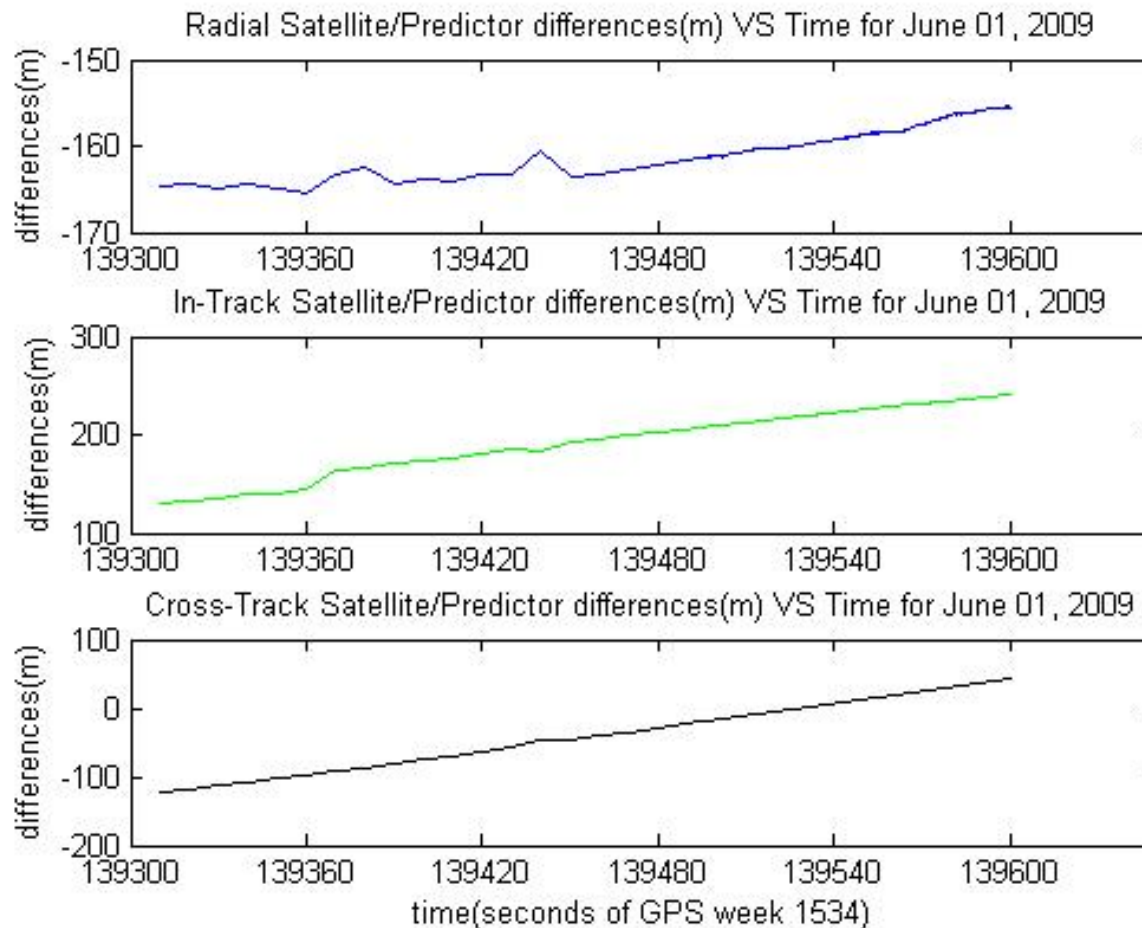
NANOPS Orbit-Testing Results

- Fuel Leakage: Negligable
- ISP: ~46s
- Minimum Impulse Bit: ~0.13 mNs
- Valve on-time (testing to date): 1ms - 500ms

Upcoming NANOPS testing

- Constant thrust
- **Pulse-Width Modulation thrusting**
 - PWM regulator valve to thrust at quasi-constant pressures

GPS Occultation



- Position difference (radial, in-track, cross-track) between GPS receiver relative to TLE-estimated ground track on the order of several hundred meters