Flight Results from the nSight-1 QB50 CubeSat Mission

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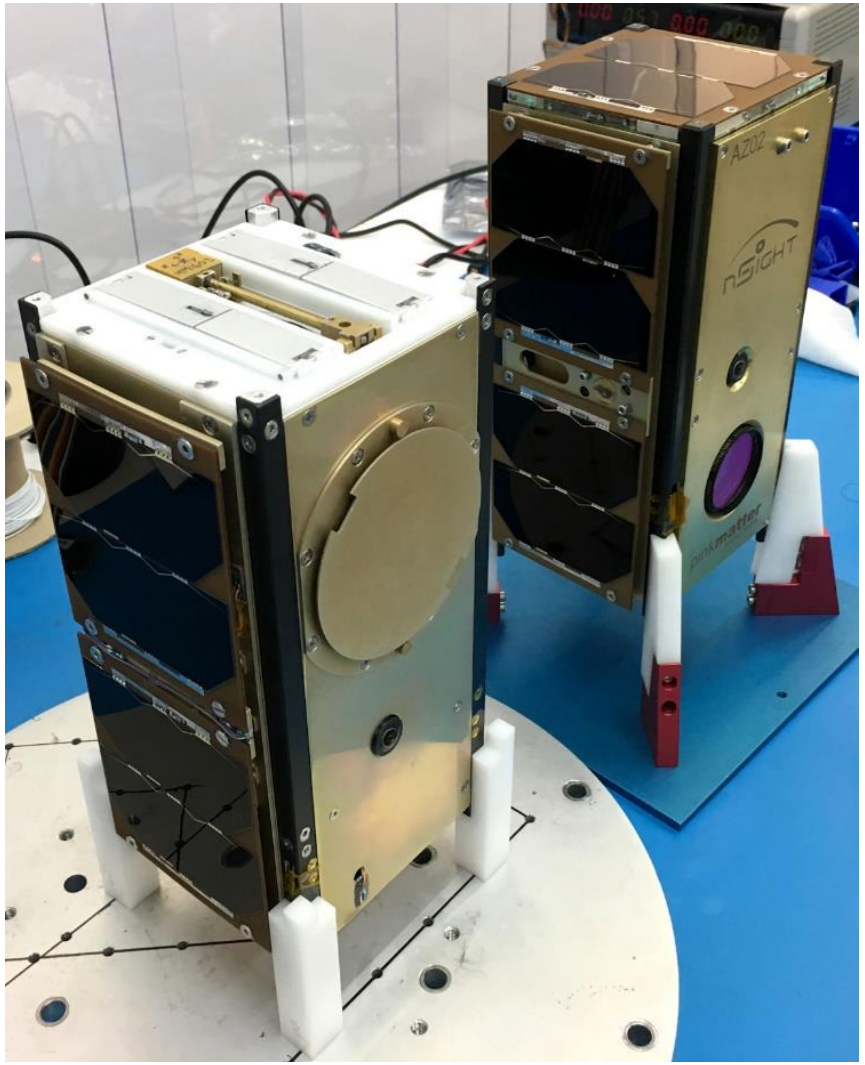
nSight-1: The Story

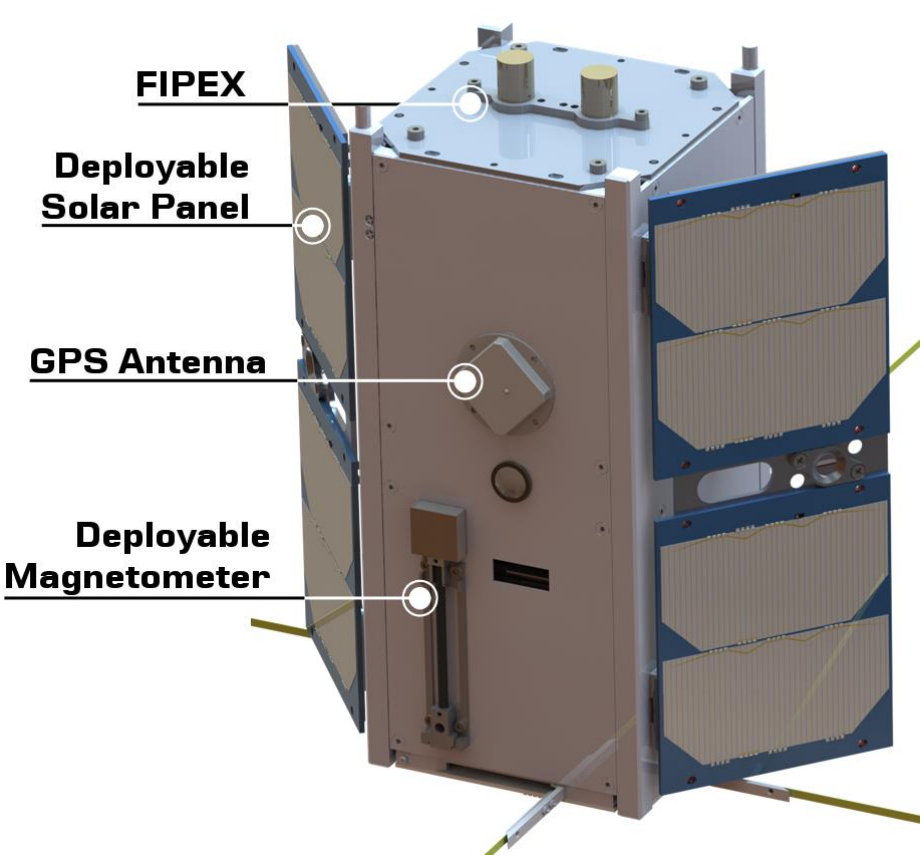
- Built by SCS-Space in South Africa
- Late entry to QB50 – nSight-1 project started in 2016
- Testbed for in-house developed “Gecko” Earth imager
- Short time-to-develop
  - Use COTS sub-systems where possible
  - Borrow from partners – CubeSpace and Stellenbosch University
- ZA-AeroSat: Stellenbosch University CubeSat, built for QB50
- QB50 ADCS Units – Delivered by Stellenbosch University and University of Surrey to QB50
- ADCS Hardware has since been commercialised by CubeSpace

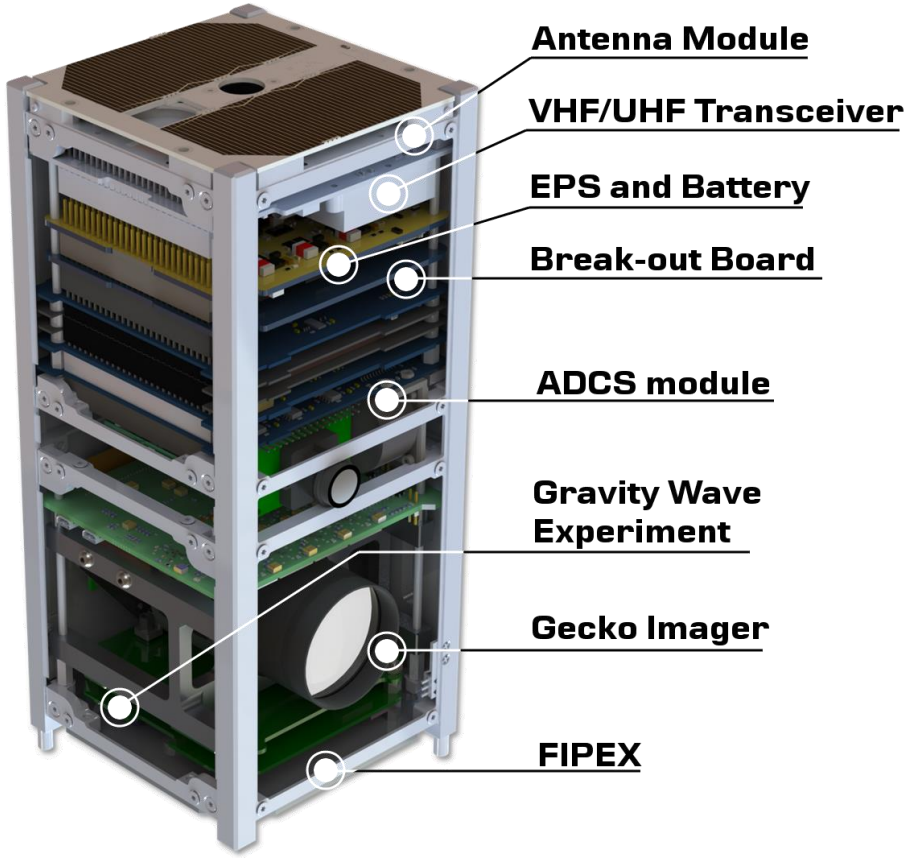


nSight-1 Layout

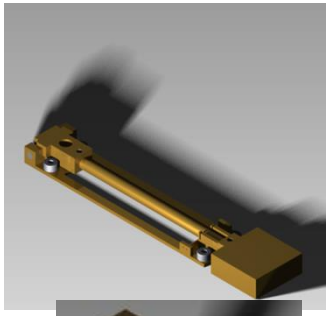
nSight-1

- COTS EPS and Communications sub-systems
- Y-momentum ADCS (CubeSpace)
- QB50 FIPEX science unit
- Gecko Imager



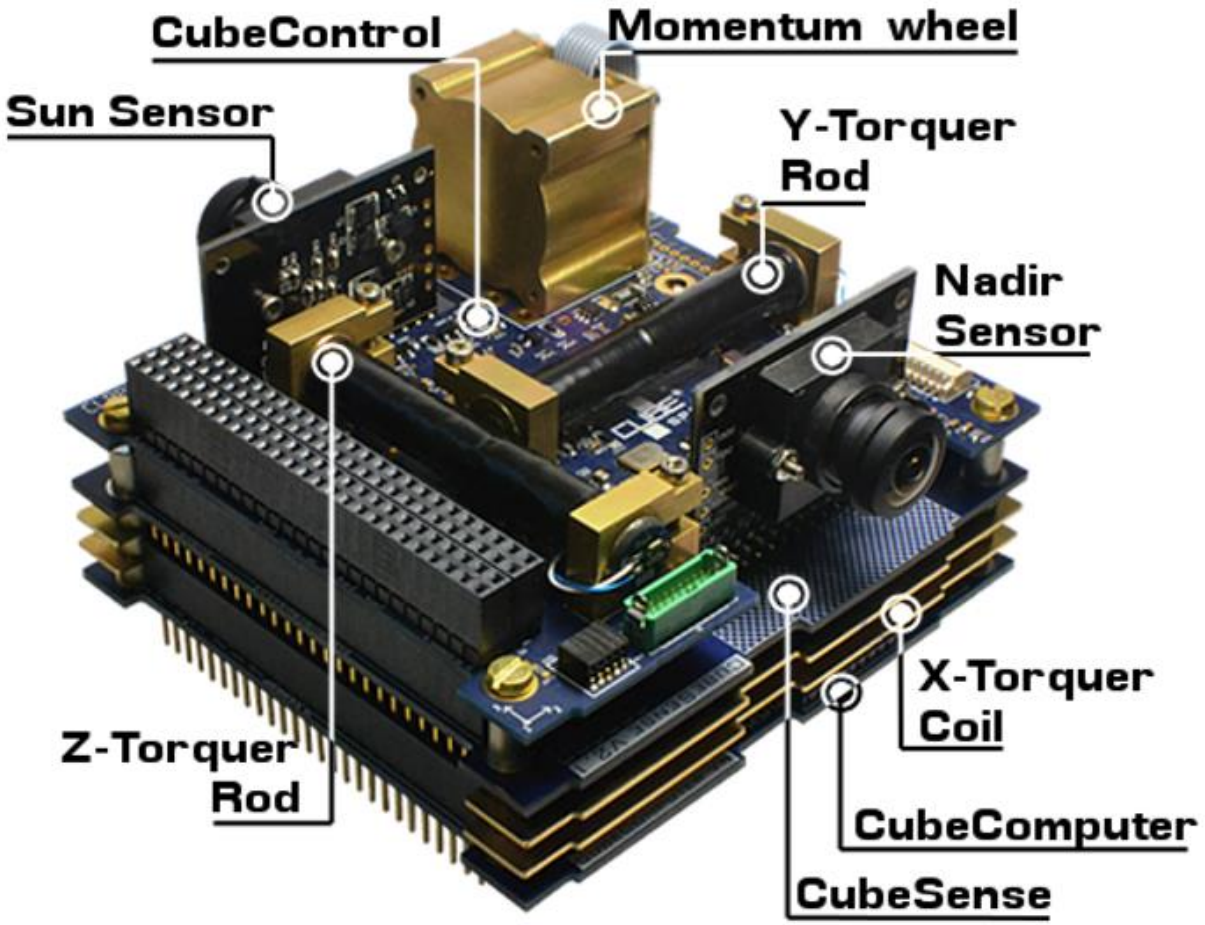


ADCS Hardware



Deployable Magnetometer

Coarse sun sensors



ADCS Bundle: Size = 95 x 90 x 56 mm, Mass = 397 gram

ADCS Sensors and Actuators Summary

ADCS Requirements

- FIPEX sensor pointing to RAM direction +/- 10 deg
- Attitude estimation accuracy +/- 2 deg
- Gecko Imager pointing to Earth

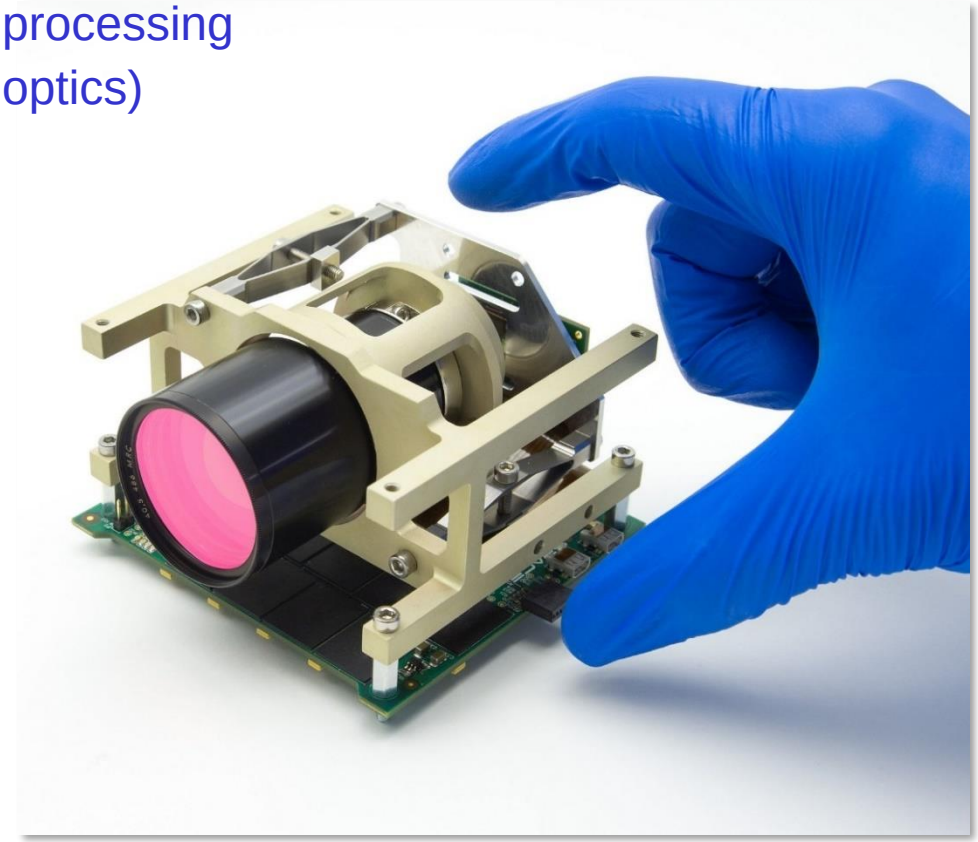
Sensors & Actuators	Type	Range / FOV	Accuracy (RMS)
Magnetometer	3-axis MagR	± 60 µT	< 40 nT
Sun Sensor	2-axis CMOS	Hemisphere	< 0.2º
Nadir Sensor	2-axis CMOS	± 45º	< 0.2º
Coarse Sun	6 Photodiodes	Full Sphere	< 10º
Rate Sensor	MEMS	± 85º/sec	< 0.05 deg/sec
Momentum Pitch wheel	BDC Motor	± 1.7 milli-Nms	< 0.001 milli-Nms
Magnetorquers	Ferro-magnetic rods & air coil	± 0.2 Am^2	< 0.0005 Am^2 (remanence)

SCS Gecko Imager

Gecko Earth Imager

- Modular design
- Compatible with CubeSats
- High-speed high-capacity mass data storage
- FPGA processor for real-time image processing
- High frame rate capability (for larger optics)

Characteristics	
Form factor	< 1U
Mass	< 480 g
GSD	31 m from ISS orbit
Image Sensor	2.2 Megapixel RGB
Storage	128 GB
Rad. tolerance	Tested to 30 krad TID
Space heritage	2017 !



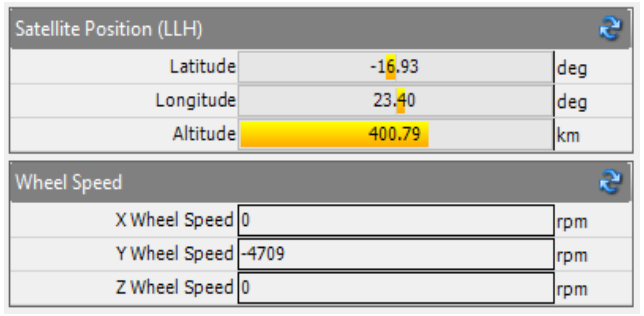
Command and Telemetry Interface

- XML file – defines command and telemetry interface
- Generate flight software source code from XML interface definition
- Generate ground software source code (classes) and also user interface elements from XML interface definition
- Changes to interface occur only in one place (the XML markup) – eliminates the possibility of “copy and paste” errors

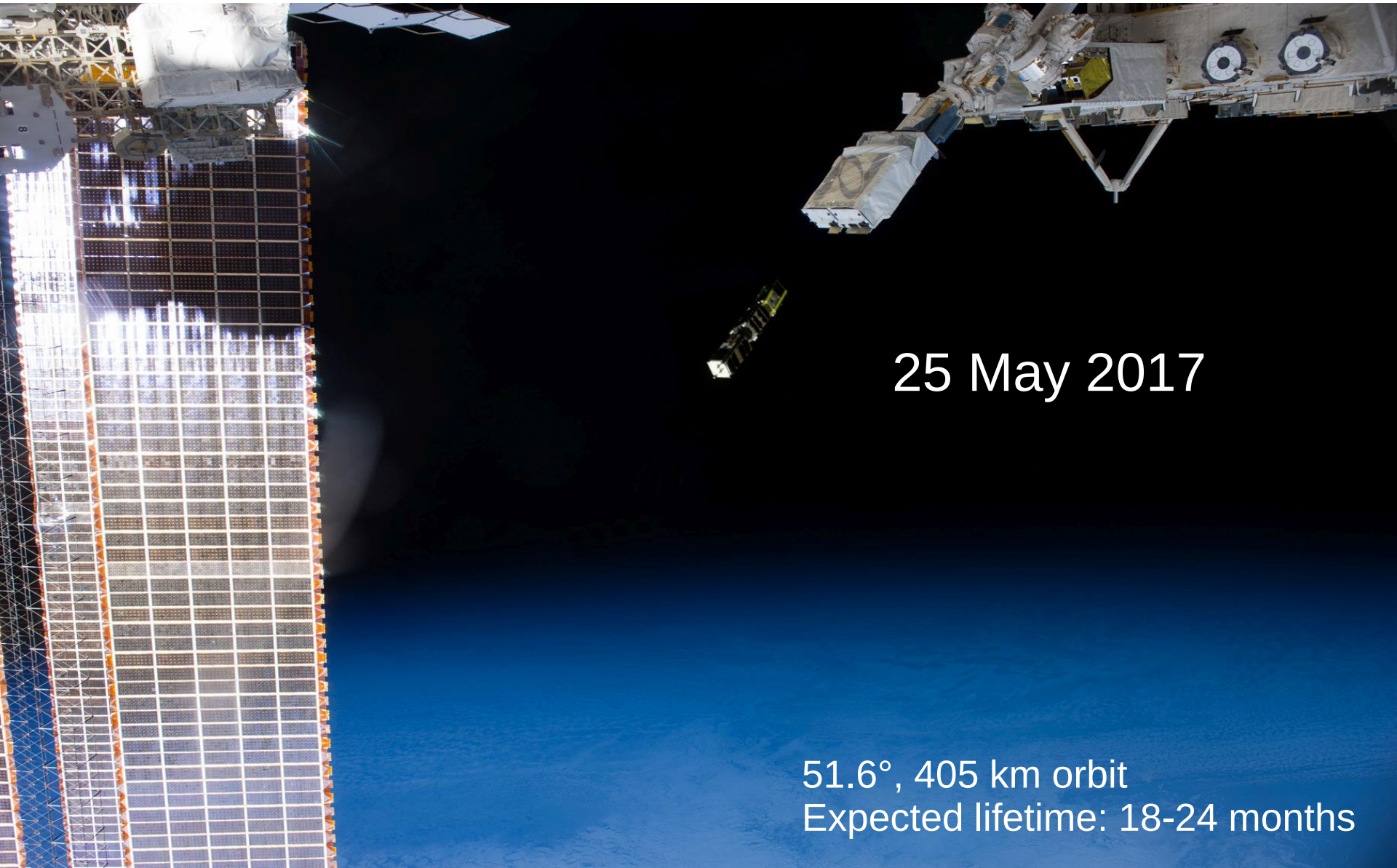
```
  <Ttcs CanSet="false" CanGet="true" CodeName="PositionLLH" DisplayName="Satellite Position (LLH)"
Description="Satellite position in WGS-84 coordinate frame" Len="6" >

      <Item CodeName="Latitude" DisplayName="Latitude" Description="WGS-84 Latitude angle " BitOffset="0"
BitLength="16" ValueType="SignedInteger" CalibrationUserToRaw="USERVAL*100.0"
CalibrationRawToUser="RAWVAL*0.01" MeasurementUnit="deg" />

      …

  </Ttcs>
```

PositionLLH | 151 | 30 | Satellite Position (LLH) | Satellite position in WGS-84 coordinate frame | ADCS State | 6 | part of AdcsState

Bit Offse	Bit Len	Name (source code)	Display Name	Description	Value Type	Enumeration	Calibration (User to Raw)	Calibration (Raw to User)	Unit
288	16	Latitude	Latitude	WGS-84 Latitude angle	SignedInteger		RAWVAL*0.01	USERVAL*100.0	deg
304	16	Longitude	Longitude	Longitude angle	SignedInteger		RAWVAL*0.01	USERVAL*100.0	deg
320	16	Altitude	Altitude	WGS-84 altitude	UnsignedInteger		RAWVAL*0.01	USERVAL*100.0	km

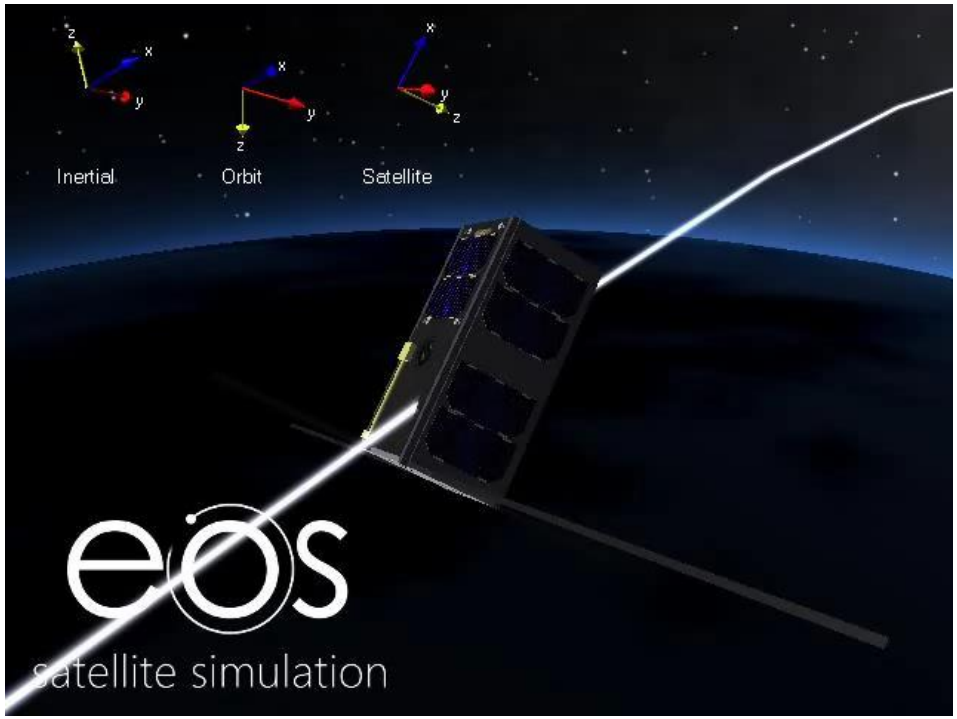


Deployed from the ISS



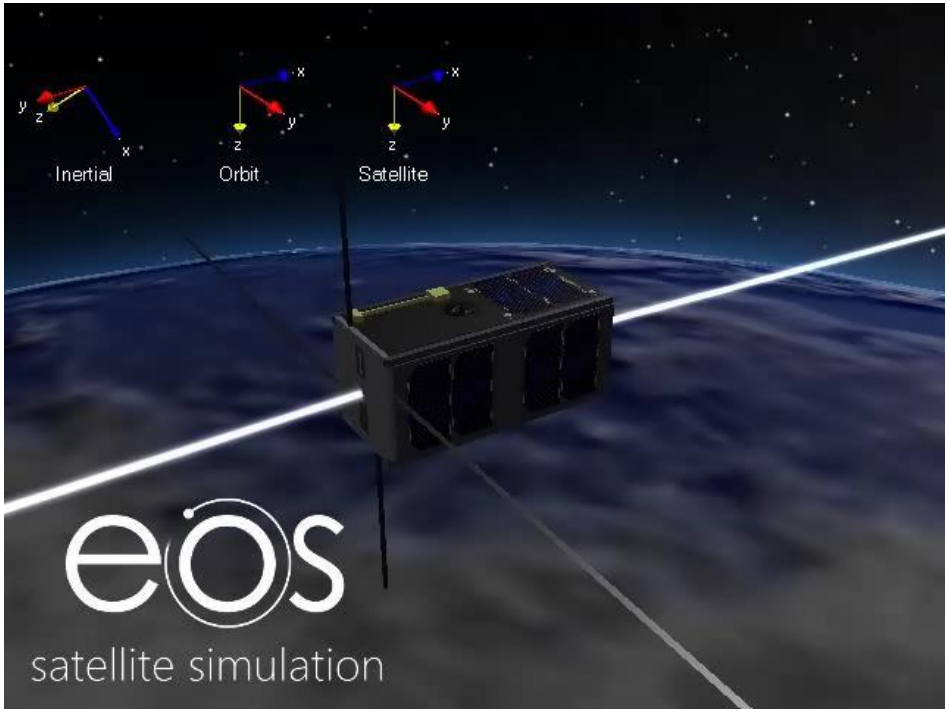
Detumbling Control Mode

- Bdot Magnetic Control
  - Damp X/Z-body rates
  - Align Y-body axis with orbit normal
- Y-Thompson Spin Control
  - Set Y-body rate at -3 º/sec
- Measures Y-rate with MEMS rate sensor or Rate Kalman Filter
- Magnetic moment is pulse width modulated by switching 3-axis magnetorquers

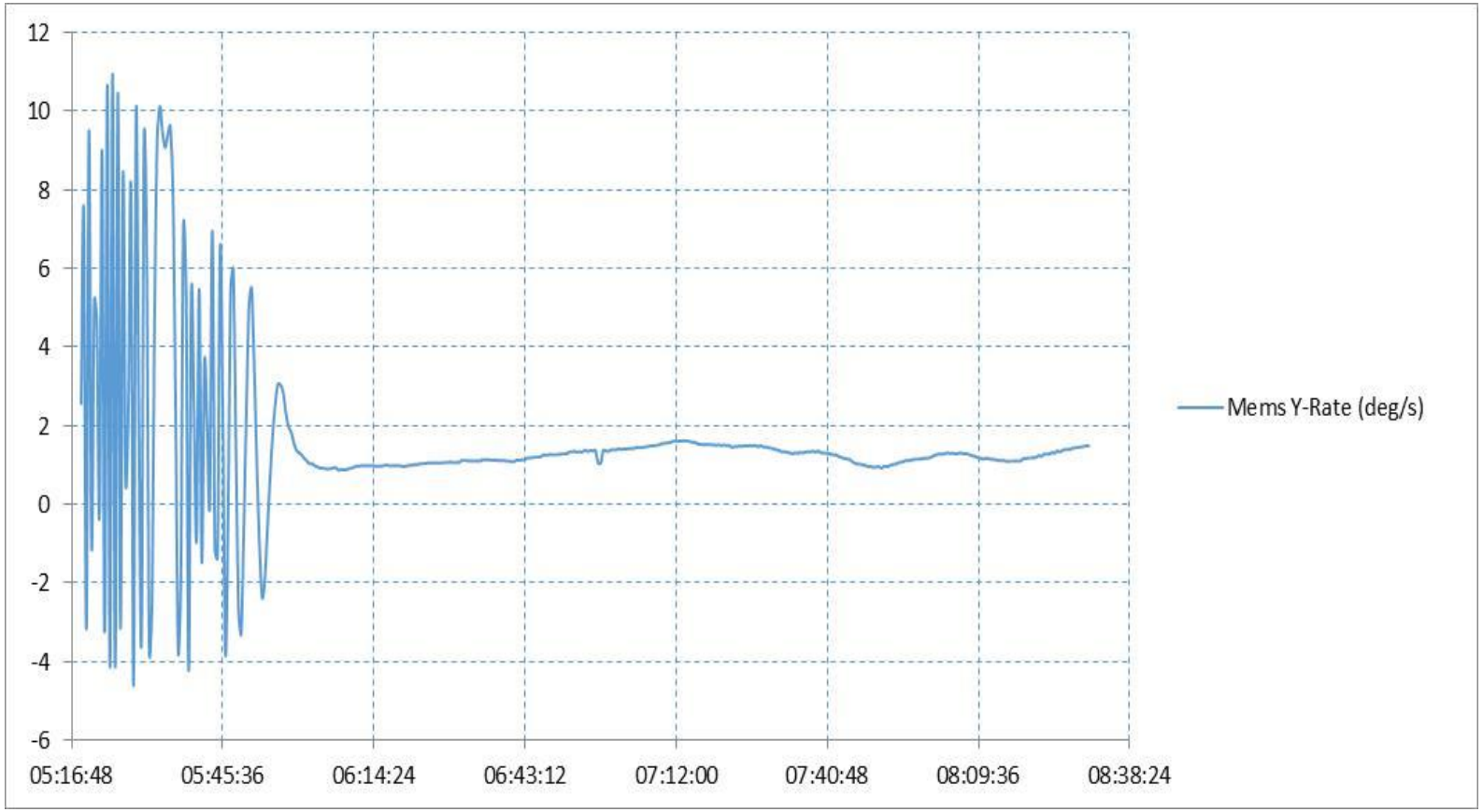


Y-Wheel Mode (3-Axis stabilised)

- Extended Kalman Filter
  - Full state estimation from vector measurements
  - Model vectors in ORC frame (sun, nadir, B-field)
- Y-momentum wheel controller
  - X-product Magnetic controller to manage Y-wheel momentum at -1 milli-Nms and damp roll & yaw:
- PD controller for Y-wheel to control body pitch axis



Bdot detumbling result



Detumbling result as measured by the MEMS Y-Rate sensor, fully detumbled in less than 1 hour

02/06/2017

Magnetometer Calibration

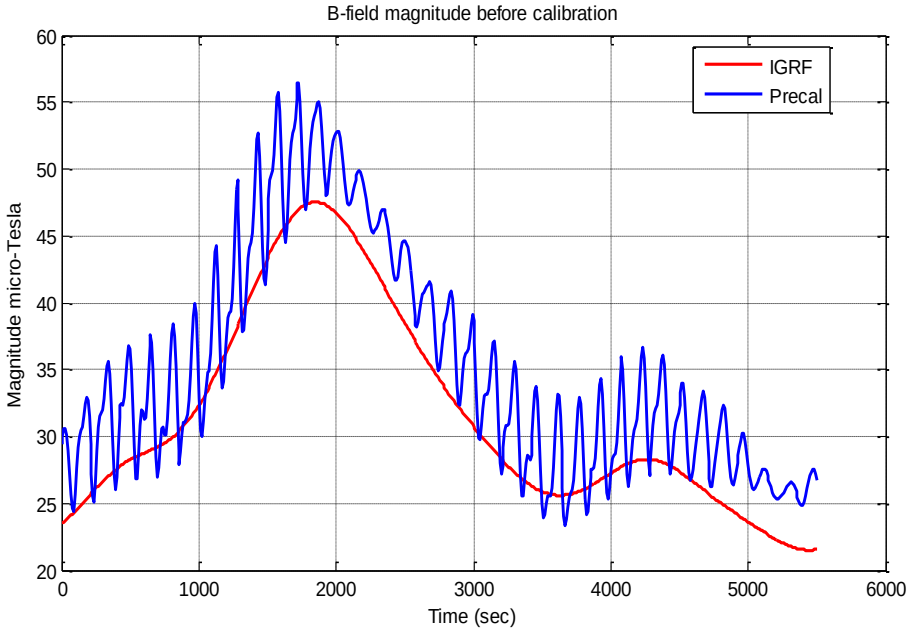
- Pre-launch calibration
  - Determine its bias and sensitivity (gain) calibration coefficients per axis
    - ✓ Use Helmholz coil and accurate reference magnetometer
  - Determine the magnetometer's temperature sensitivity
    - ✓ Especially for Magneto-restrictive and –inductive types

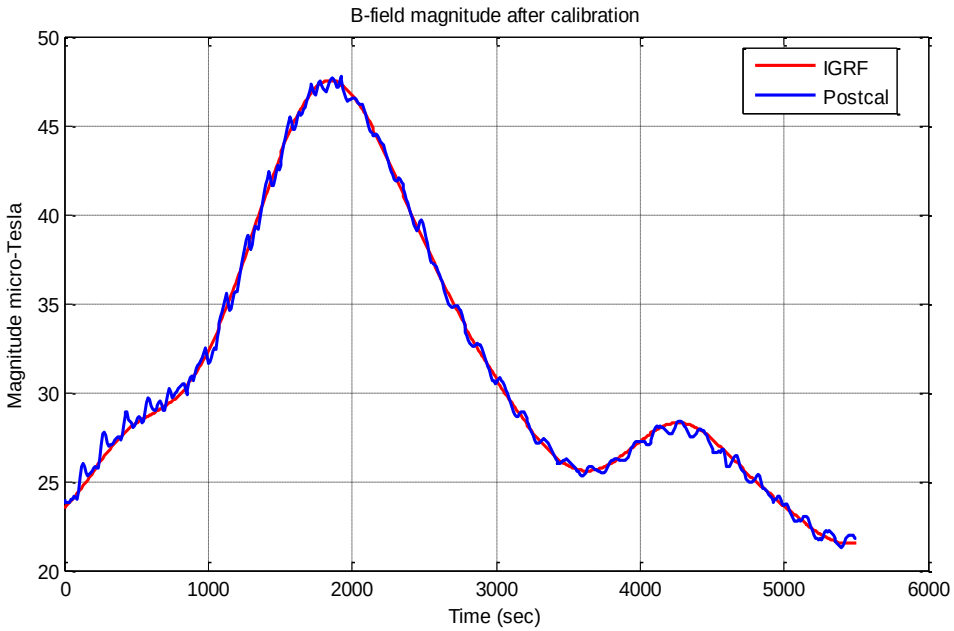
$$\mathbf{B}_{cal}(k) = \mathbf{G}_{cal}\left[\mathbf{B}_{raw}(k) - \mathbf{O}_{cal}\right]$$

- Post-launch calibration
  - Sample a WOD file with raw magnetometer measurements every 10 sec for at least an orbit, while tumbling around all axes
  - Compare the measurement vector magnitude with the time corresponding IGRF vector magnitude
    - ✓ Use an EKF [*] for attitude-independent estimation of the bias vector and gain matrix best-fit calibration parameters
  - Will also compensate for alignment errors (cross-coupling between axes

[*] J.L. Crassidis, K-L Lai & R.R. Harman, *Real-Time Attitude-Independent Three-Axis Magnetometer Calibration*, AIAA Journal of Guidance Control and Dynamics, Vol.28, No.1, 2005, pp.115-120.

Magnetometer Calibration Result

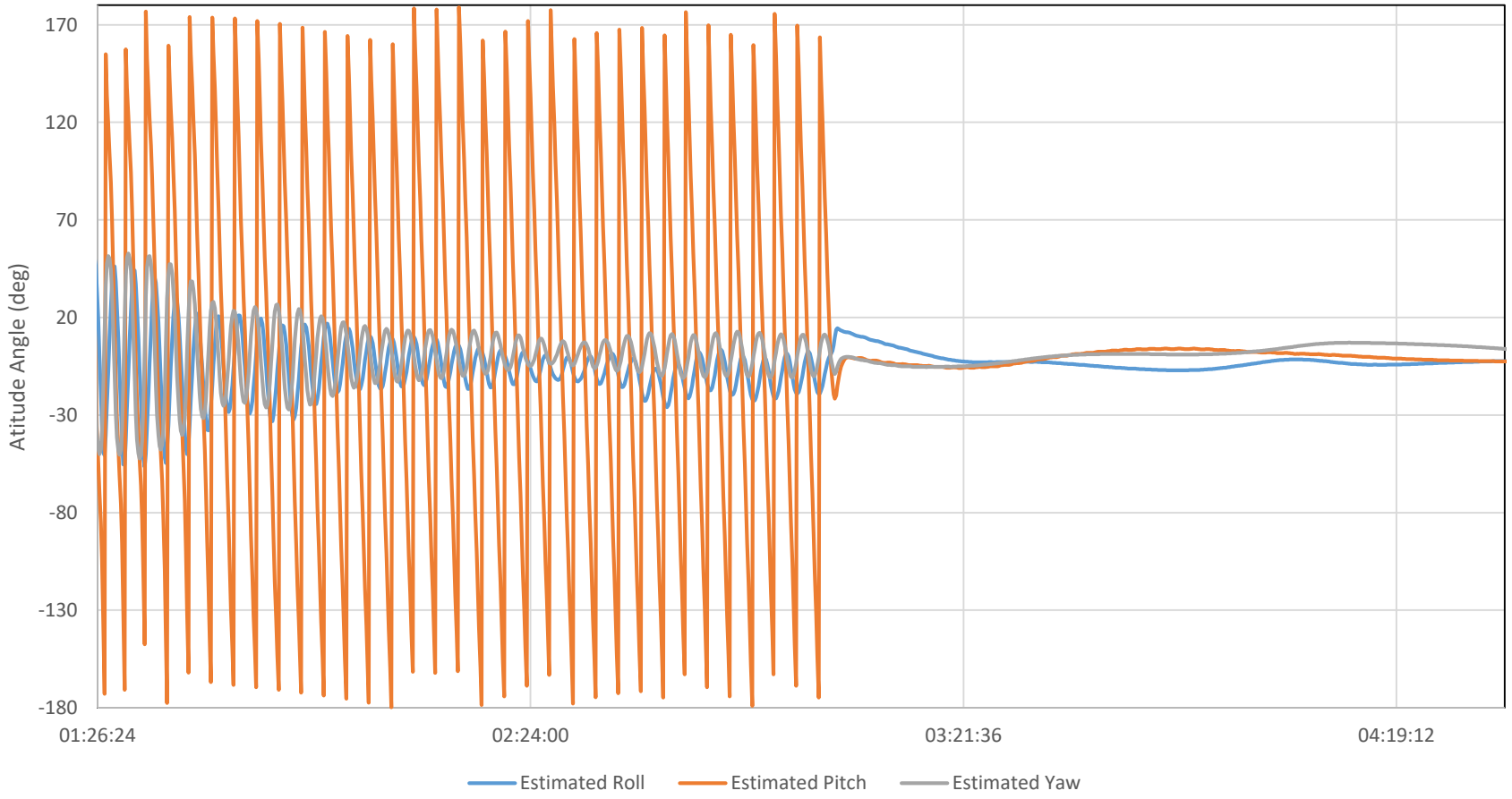




Before calibration
(σ = 2.848 µT)

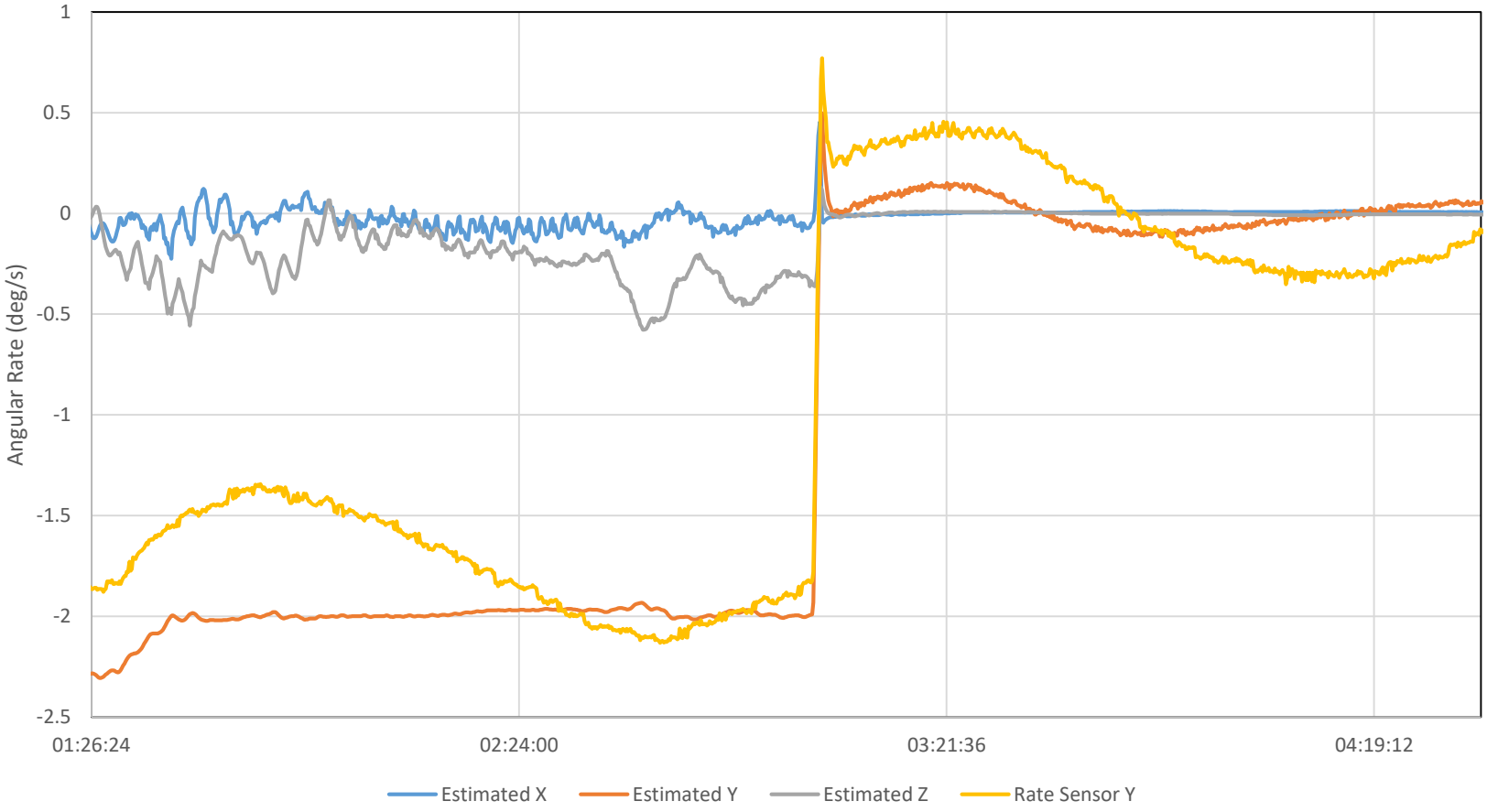
After calibration
(σ = 0.365 µT)

ADCS stabilization



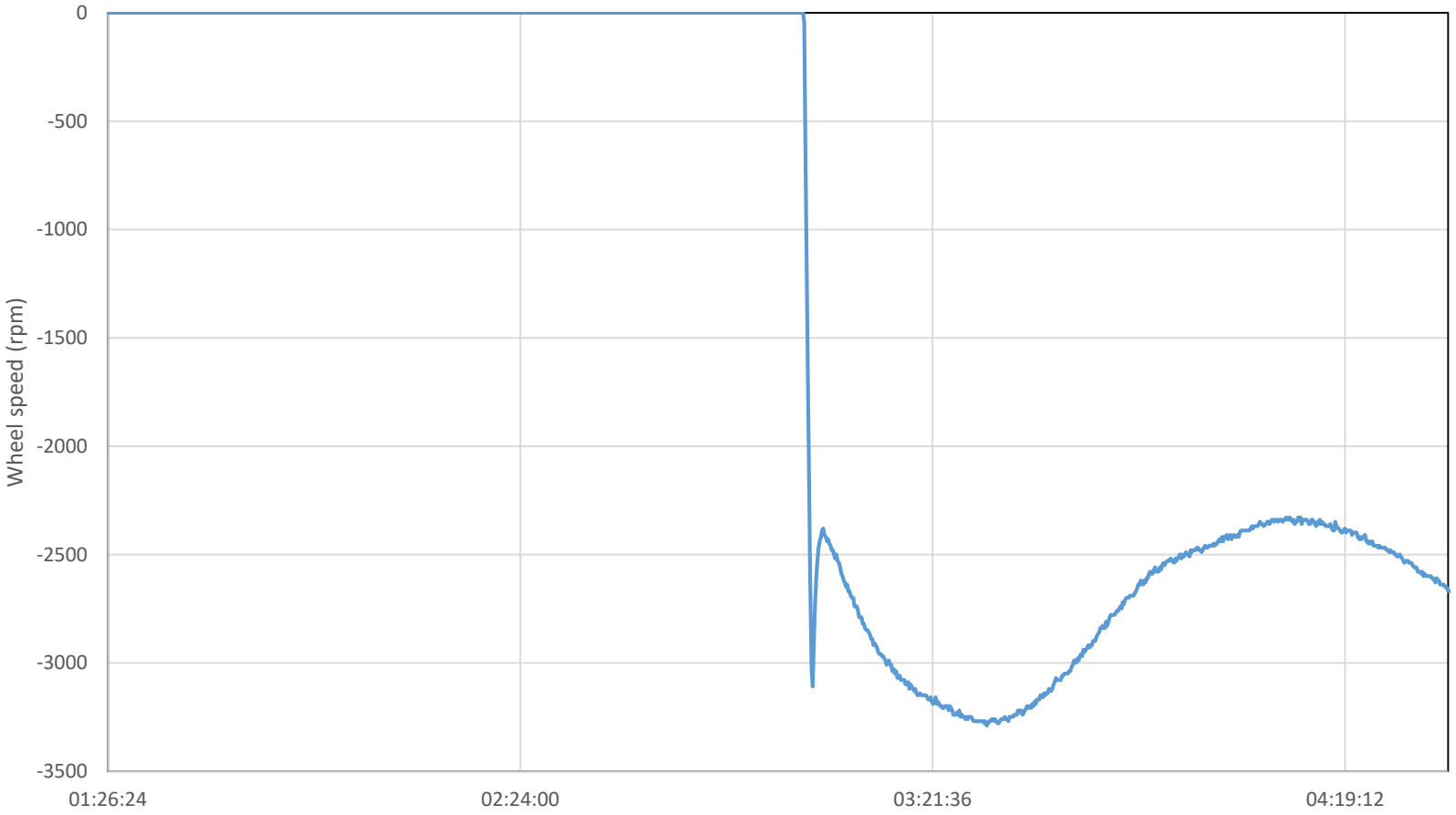
Stabilization result as estimated by the Magnetometer EKF
21/06/2017 @ 01:25:10 to 04:34:40

ADCS stabilization



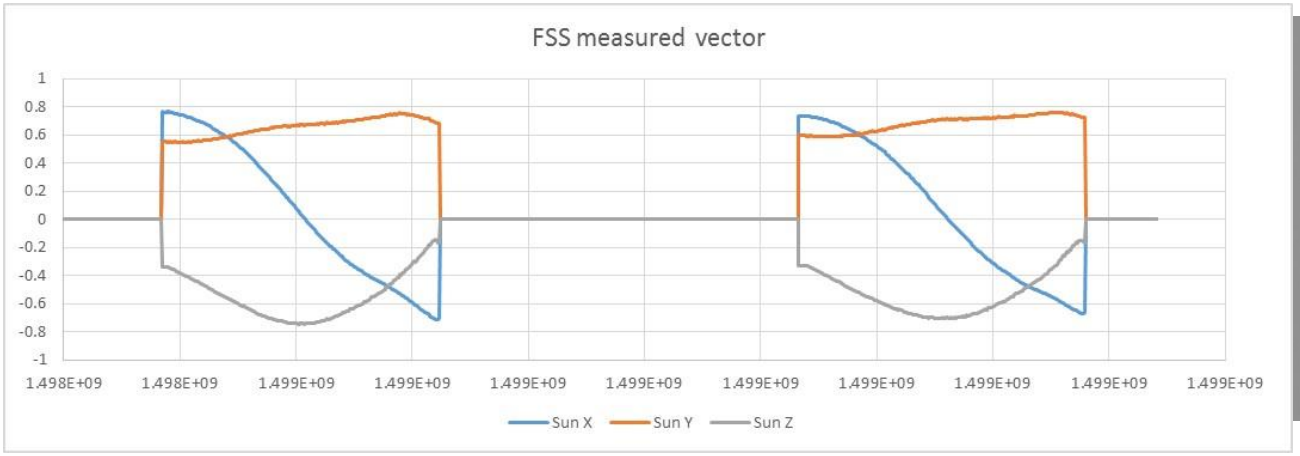
Stabilization result as estimated by the Magnetometer EKF
21/06/2017 @ 01:25:10 to 04:34:40

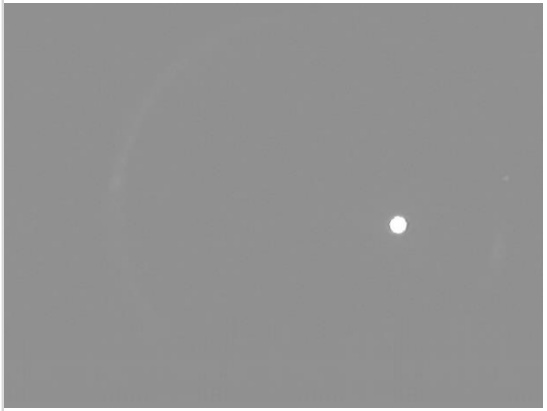
ADCS stabilization

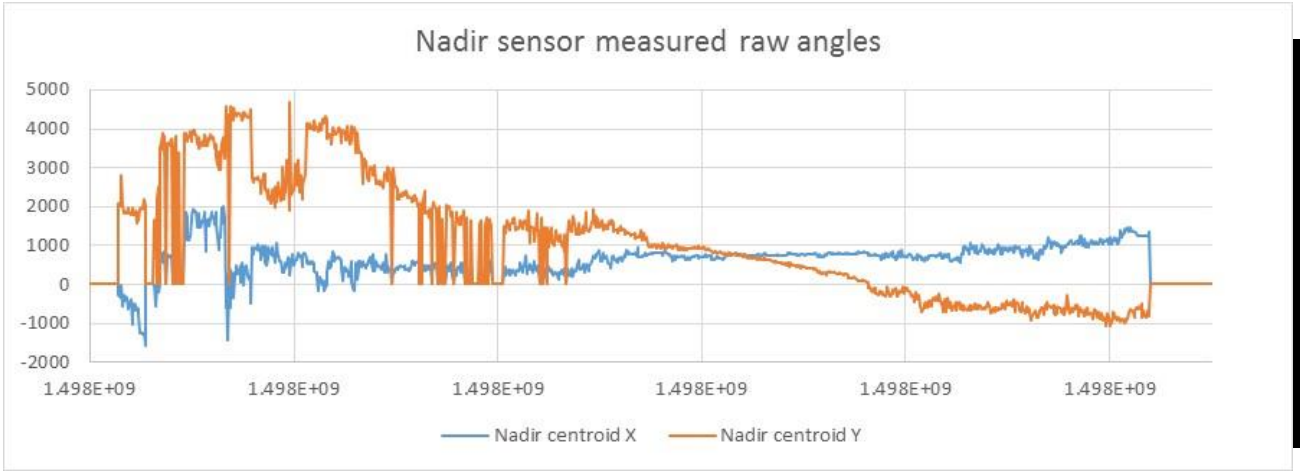


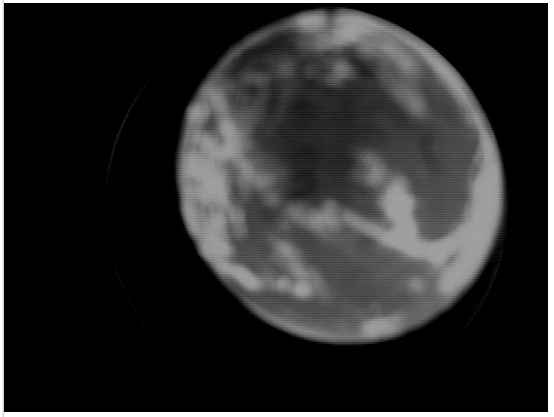
Y-Wheel speed during attitude stabilization
21/06/2017 @ 01:25:10 to 04:34:40

Sun/Nadir sensor commissioning



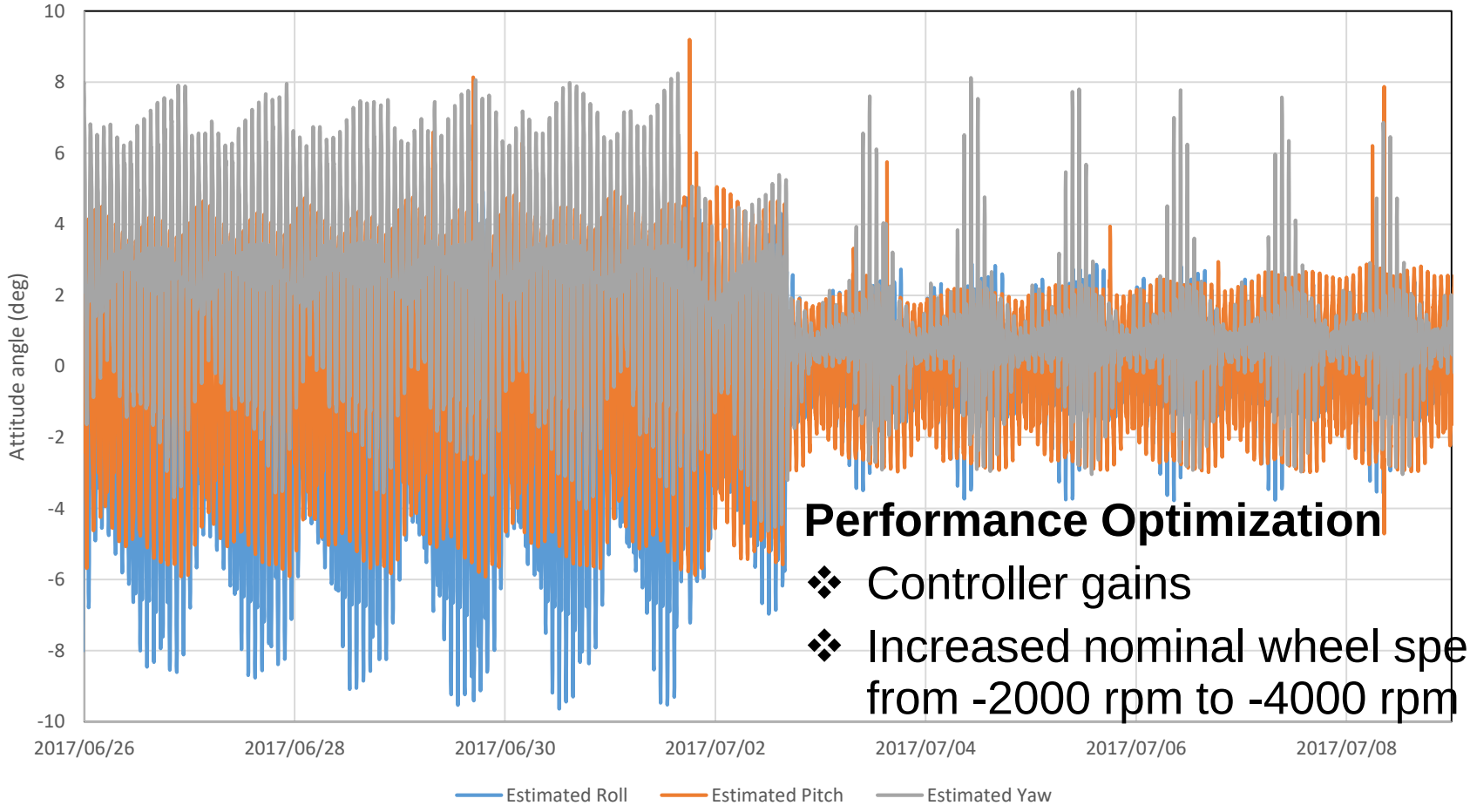






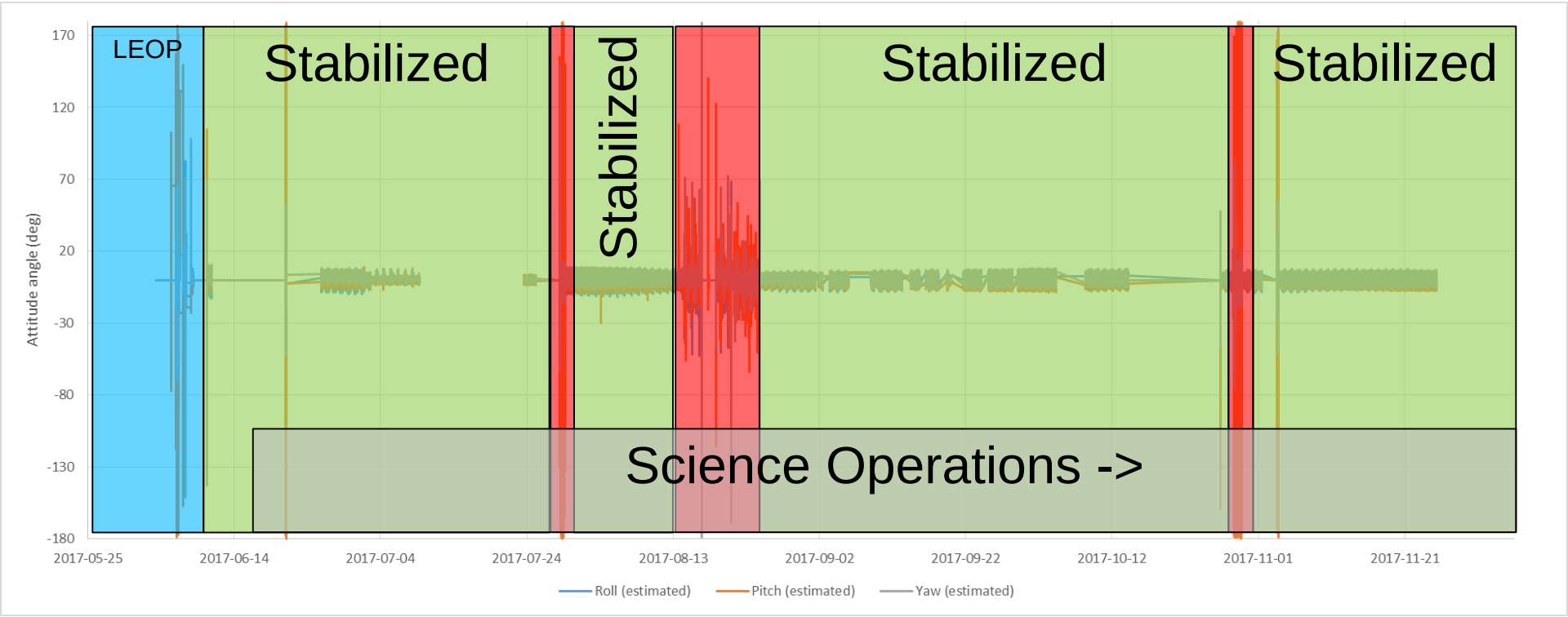
- The sun sensor works reliably, except for occasional reflections when it gives a measurement error
- The nadir sensor is slightly out of focus and the reflections from the panel opening cause measurement errors

Y-Wheel control In-flight performance



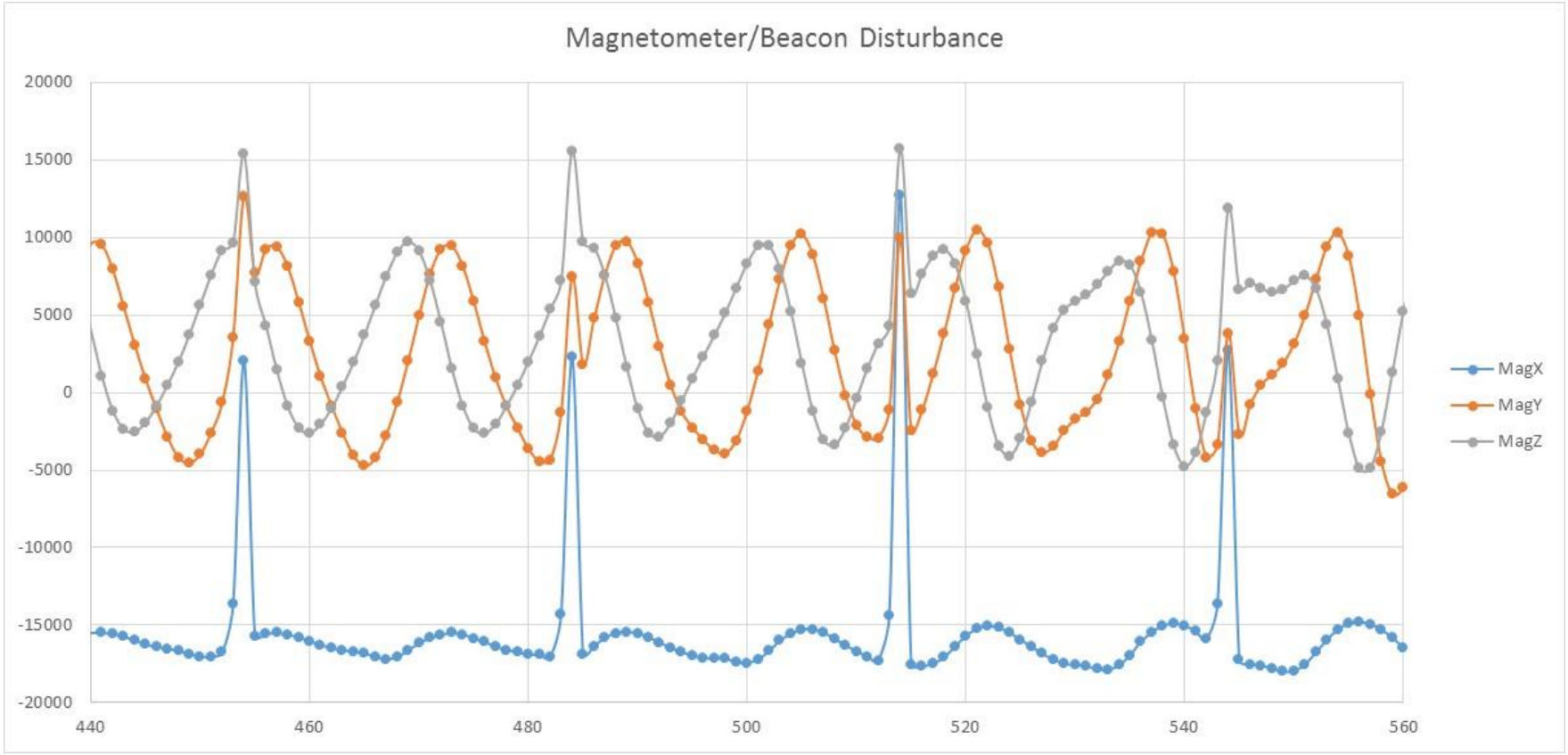
Y-Wheel momentum control over 2 week period estimated by the Magnetometer and Sun EKF
25/06/2017 to 09/07/2017

Attitude Stability Over Time



- EPS ground watchdog reset – 28 July 2017 – operator negligence
- Magnetometer lock-up – 13 to 25 Aug 2017 – transmitter EM interference
- OBC Reset – 28 Oct 2017 – Unexplained, possible SD card failure
- Stable (zero roll, pitch and yaw) attitude for >90% of mission duration
- Performing science operations since 23 Jun 2017

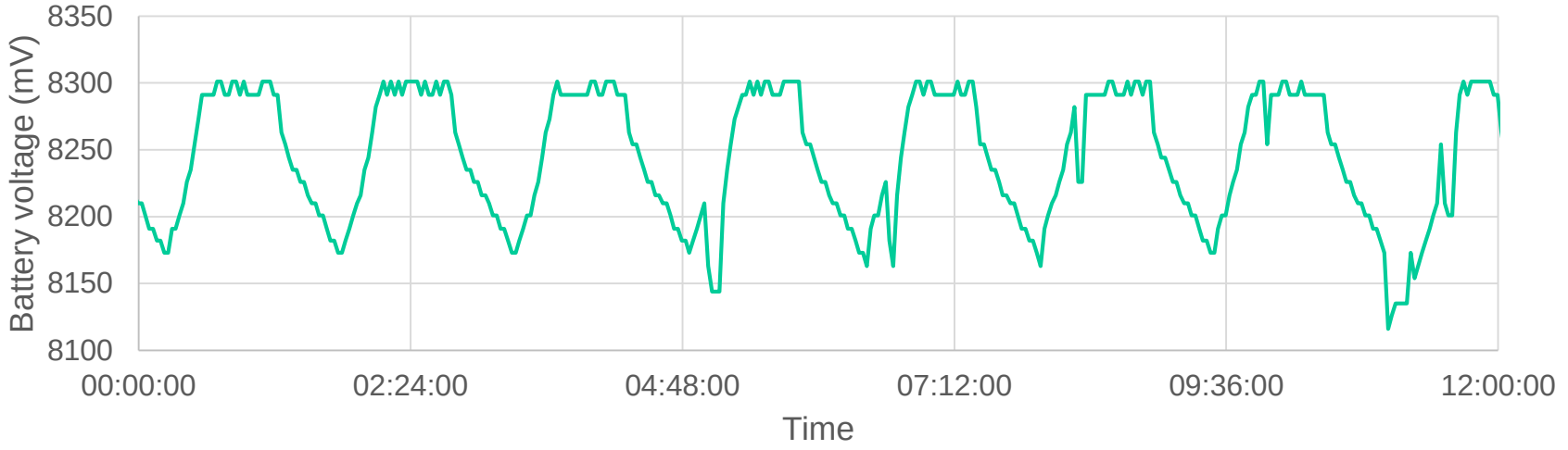
Magnetometer Disturbance

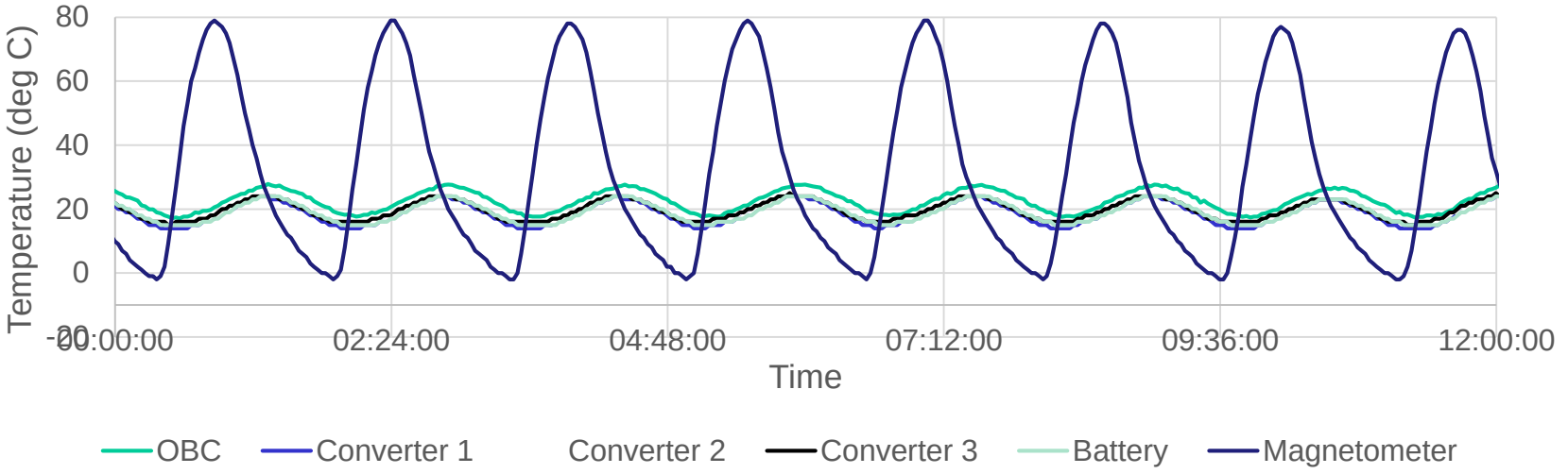


30 sec Beacon 2 watt transmitter disturbance on magnetometer measurements
01/06/2017

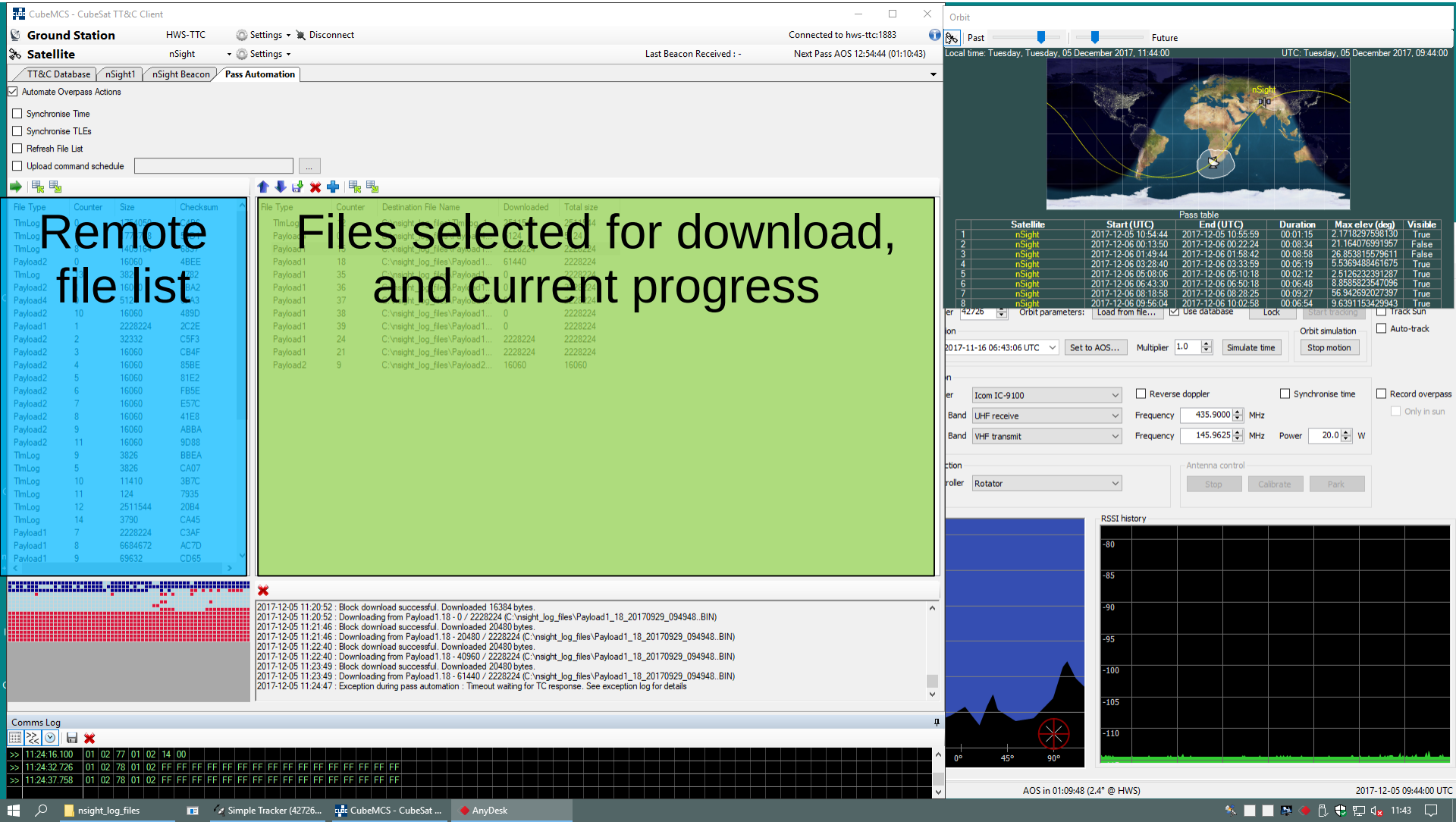
Satellite Health

Satellite house-keeping telemetry is very steady – almost boring
(23/11/2017)





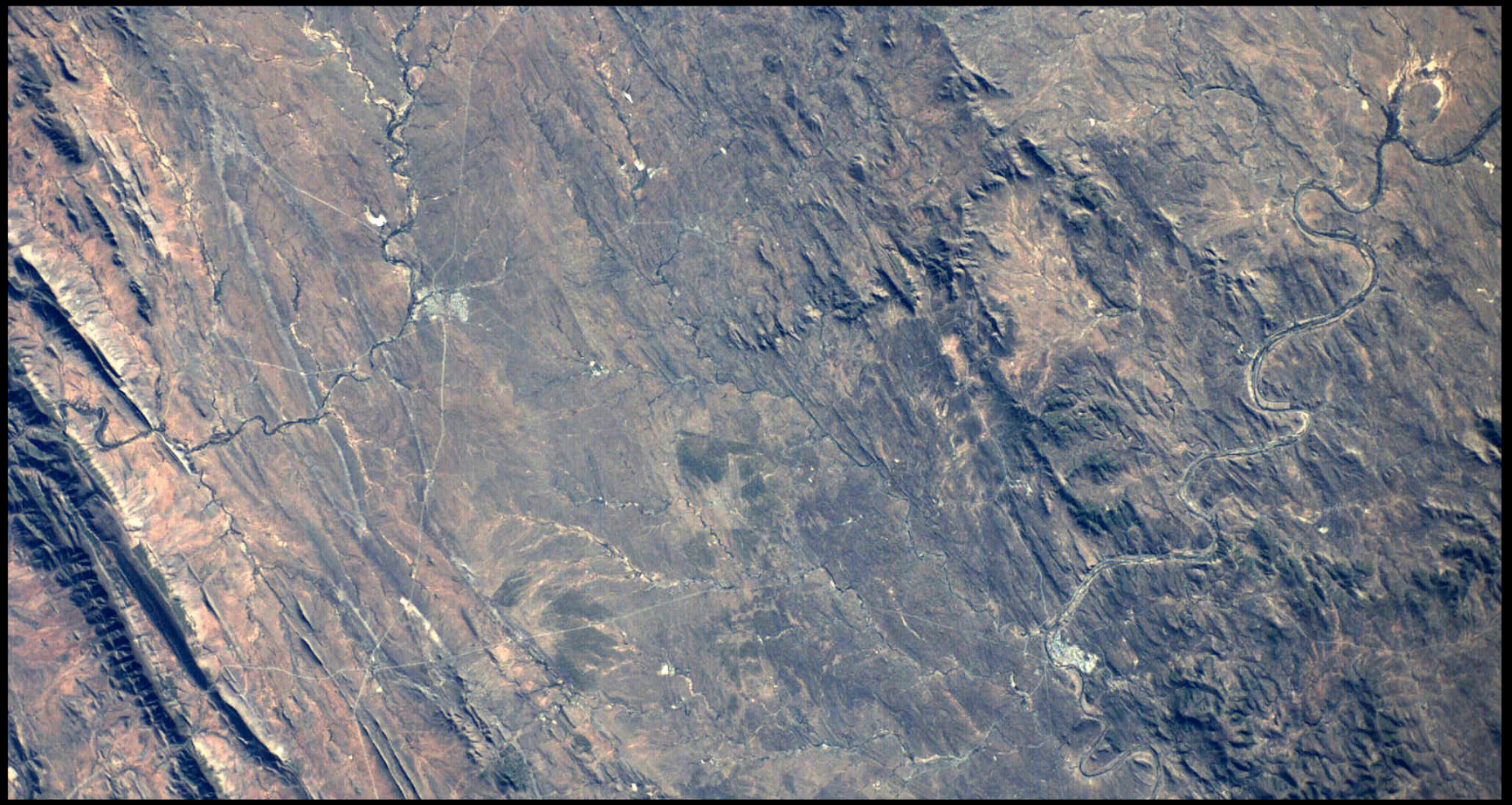
Ground Station Automation



nSight-1 Imaging

California, USA

More Imaging



Eastern Cape, South Africa

Even More Imaging

East London, South Africa

JPG vs. RAW

JPG (4:2:2 sub-sampled)

RAW

Mecca, Saudi Arabia

Multiple Overlapping Images

Vredefort Crater, South Africa

Conclusions

- nSight-1 is healthy and fully operational
- Remarkably stable and reliable
- ADCS requirements for QB50 and imaging mission has been satisfied, and ADCS performance verified

- Delivering daily science data to QB50
- Imaging electronics proven, and serves as benchmark for CubeSat imagers – also forms the basis for more capable imagers – for CubeSats and also larger satellites
- Serves as an example of what can be done in a 2U CubeSat

- Testament to growing maturity of South African space sector – majority of components manufactured locally

Salar de Uyuni, Bolivia