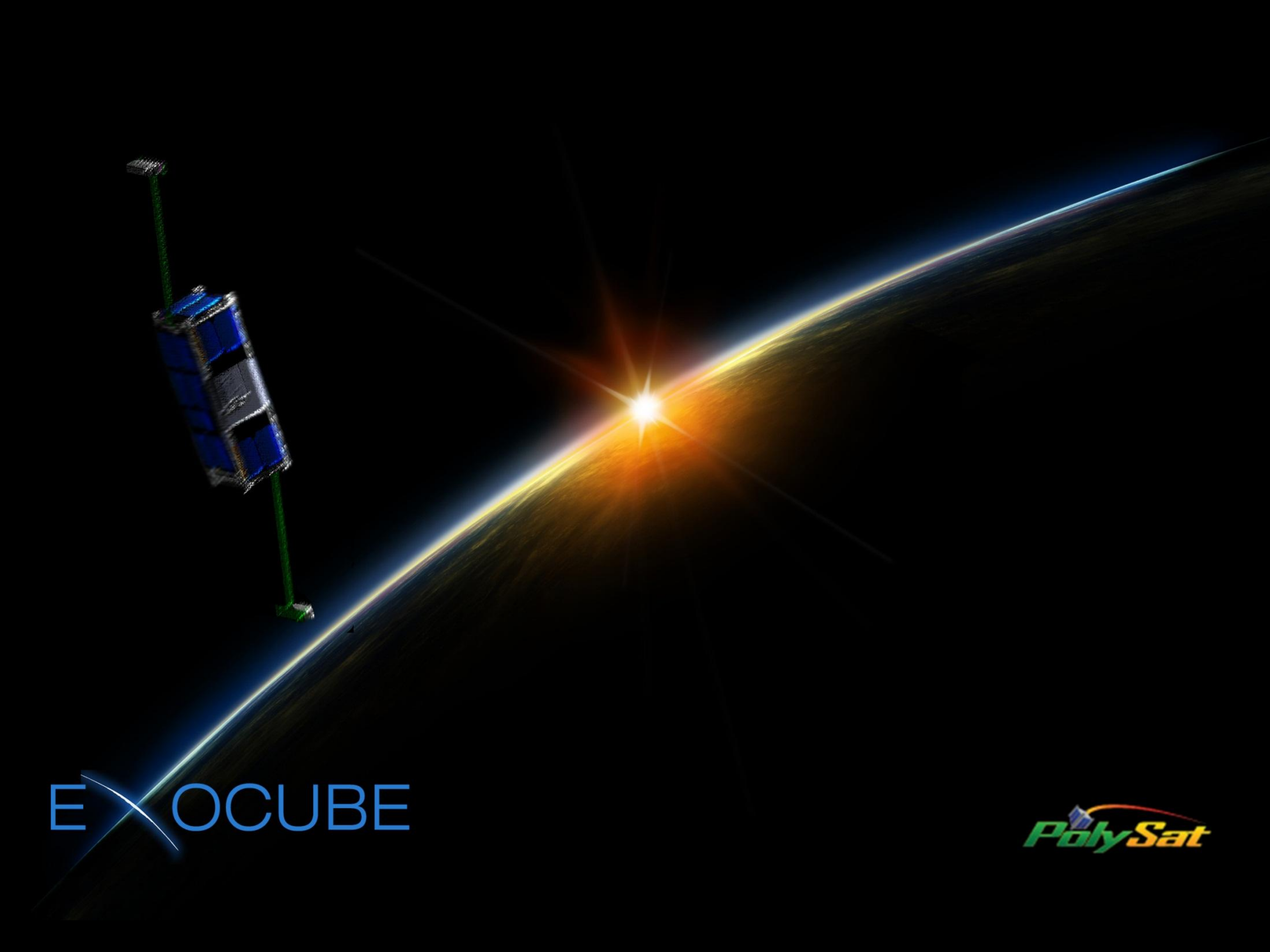
EXOCUBE
PolySat

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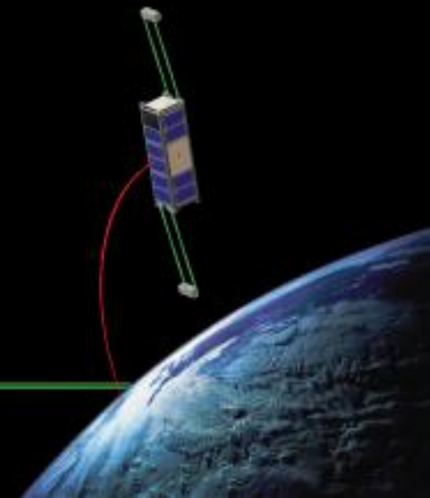
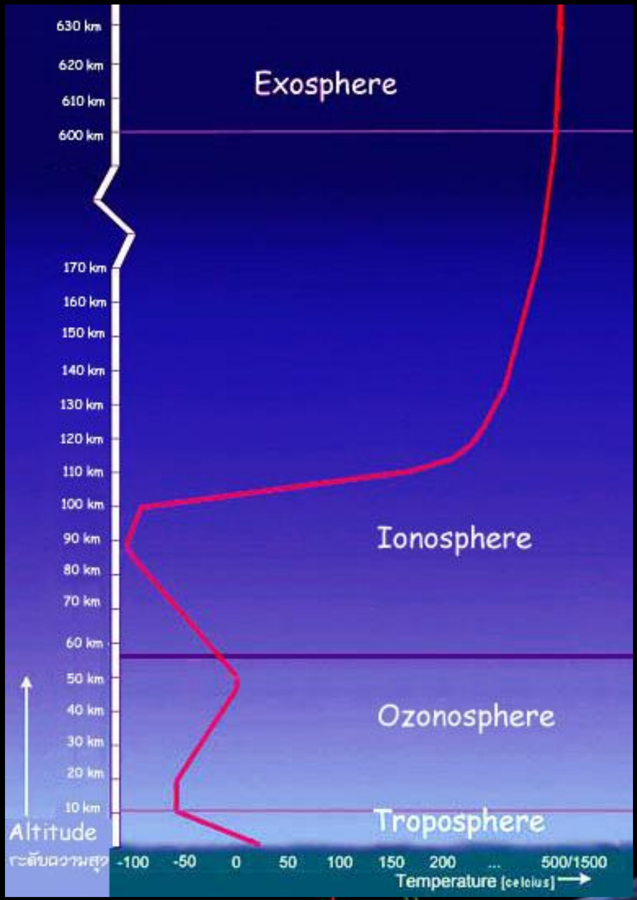


Mission Overview

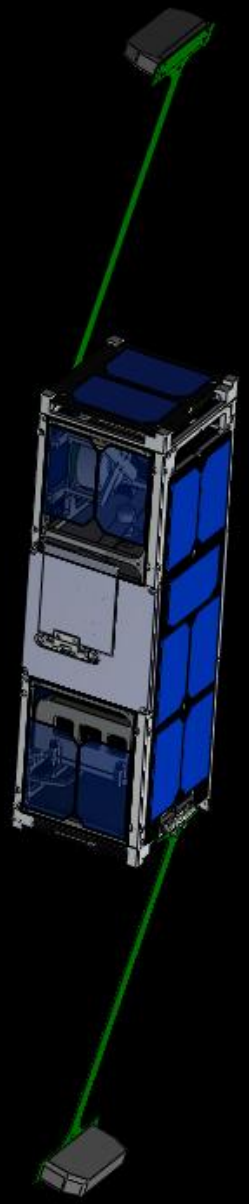
- Main Mission:
  - Measure various ions and neutrals in the Exosphere (> 600 km)
  - Payload instruments designed by NASA Goddard
  - Gather data for a 6 months -1 year

- Requirements:
  - Body rates < .1 degrees/sec
  - Nadir pointing of +/- 10 degrees
  - Ram pointing of +/- 5 degrees



Our Design: ExoCube

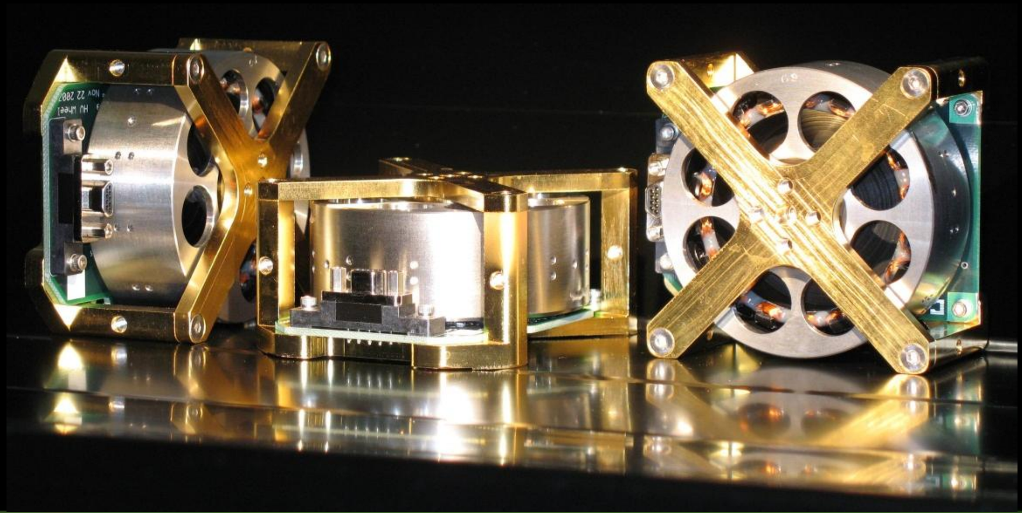
- 3U CubeSat
- Environmental Chamber
  - Houses instruments
  - Controllable doors
- Attitude Determination Control System (ADCS)
  - Gravity Gradient System with deployable booms
  - Sinclair Momentum Wheel
  - Kalman Filter with PD control law
  - Cameras for external verification



The ADCS

- Gravity gradient provides passive control
  - Helps maintain pointing and low rates with no power
  - Maintains stability during wheel spin up

- Momentum Wheel maintains stability
  - Mounted on pitch axis, couples the roll and yaw
  - Keeps pitch axis very steady and controllable
  - Running at constant speed for whole mission

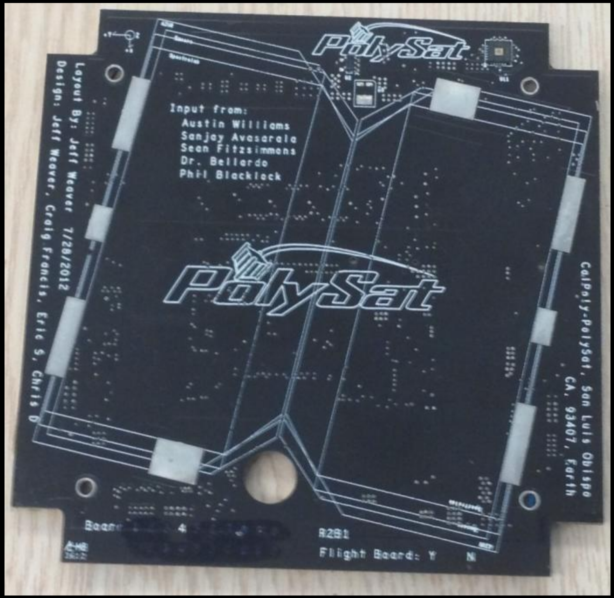


Sinclair Momentum Wheel

Hardware

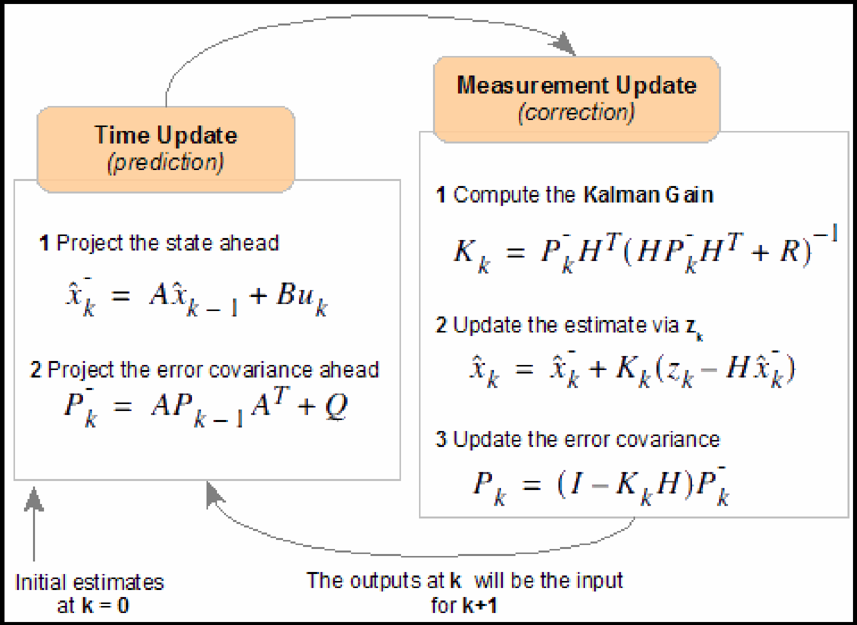
- Magnetometers
  - Read magnetic field in body frame
  - Reference IGRF model for error
- Solar Array Sensors
- Magnetorquers
  - Cal Poly's own design
- 3 MP camera
  - On both z-panels
  - 25° FOV
- Gyroscope

- All hardware has flight heritage



Z-panel with Camera Mount

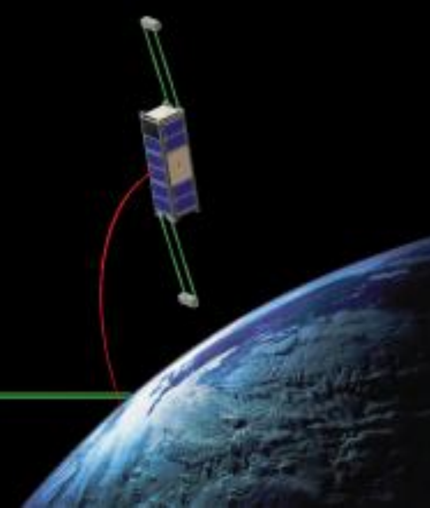
Extended Kalman Filter

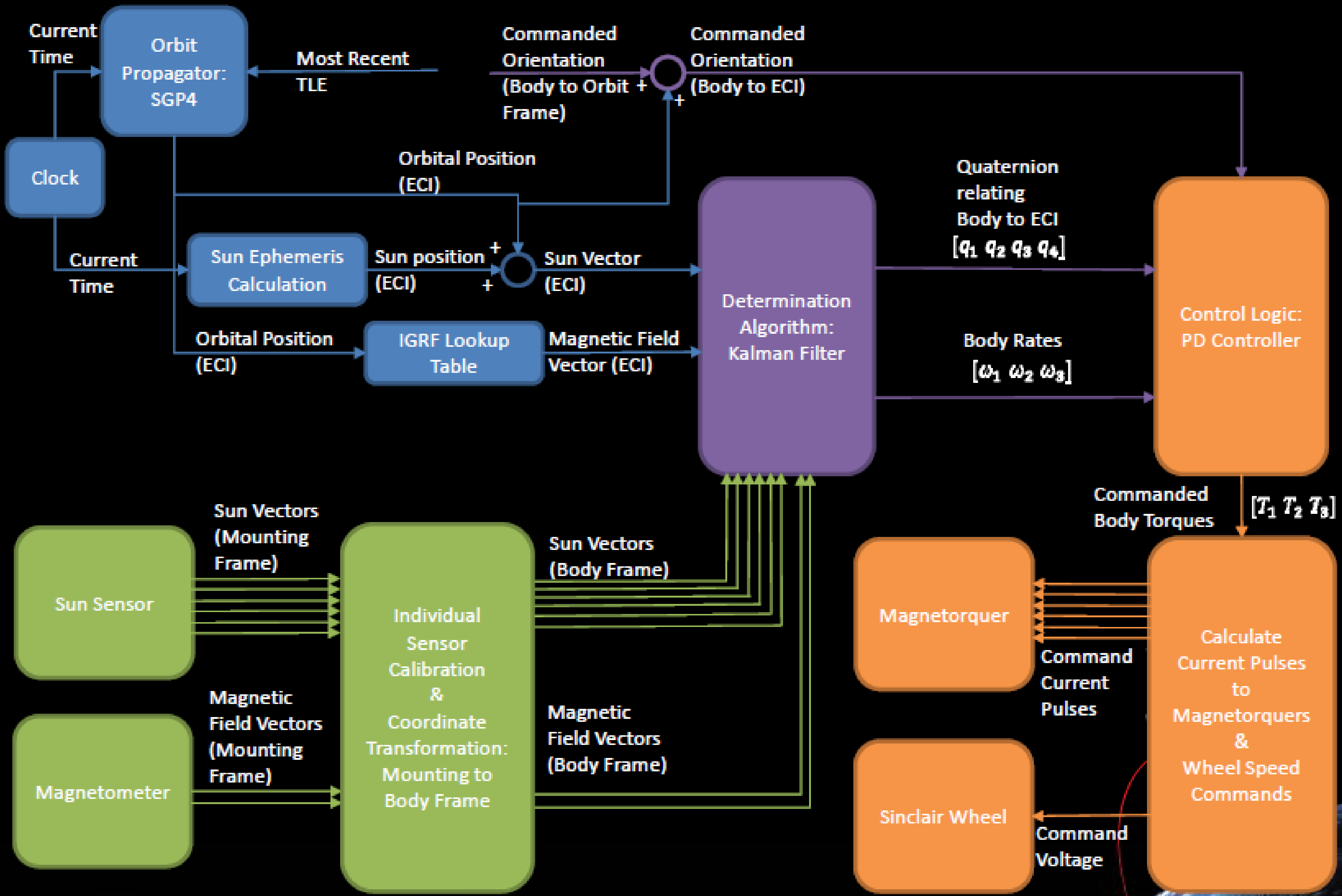


- Uses magnetometer data and solar array sensors to predict rates and quaternions
- Filters out noise and disturbances to obtain accurate rates and quaternions
- Acquire initial orientation and rates using TRIAD
- Will always be running during sensing and pulsing
- Works at: eccentricities < .1 and rates < 10 degrees/second

PD Controller

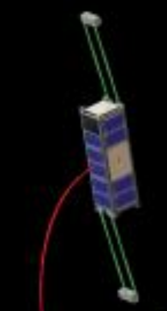
- Linear Time Invariant Control Law
  - $T_{request} = -I_{total} * (C_1 * \omega_{err} + C_3 * q_{err})$
  - $m_{command} = \frac{(B_{body} \times T_{request})}{\|B_{body}\|^2}$
  - $T_{mag} = m_{command} \times B_{body}$
- Selected for:
  - Simplicity
  - Power Efficiency
  - Proven global stability (Bong Wie)



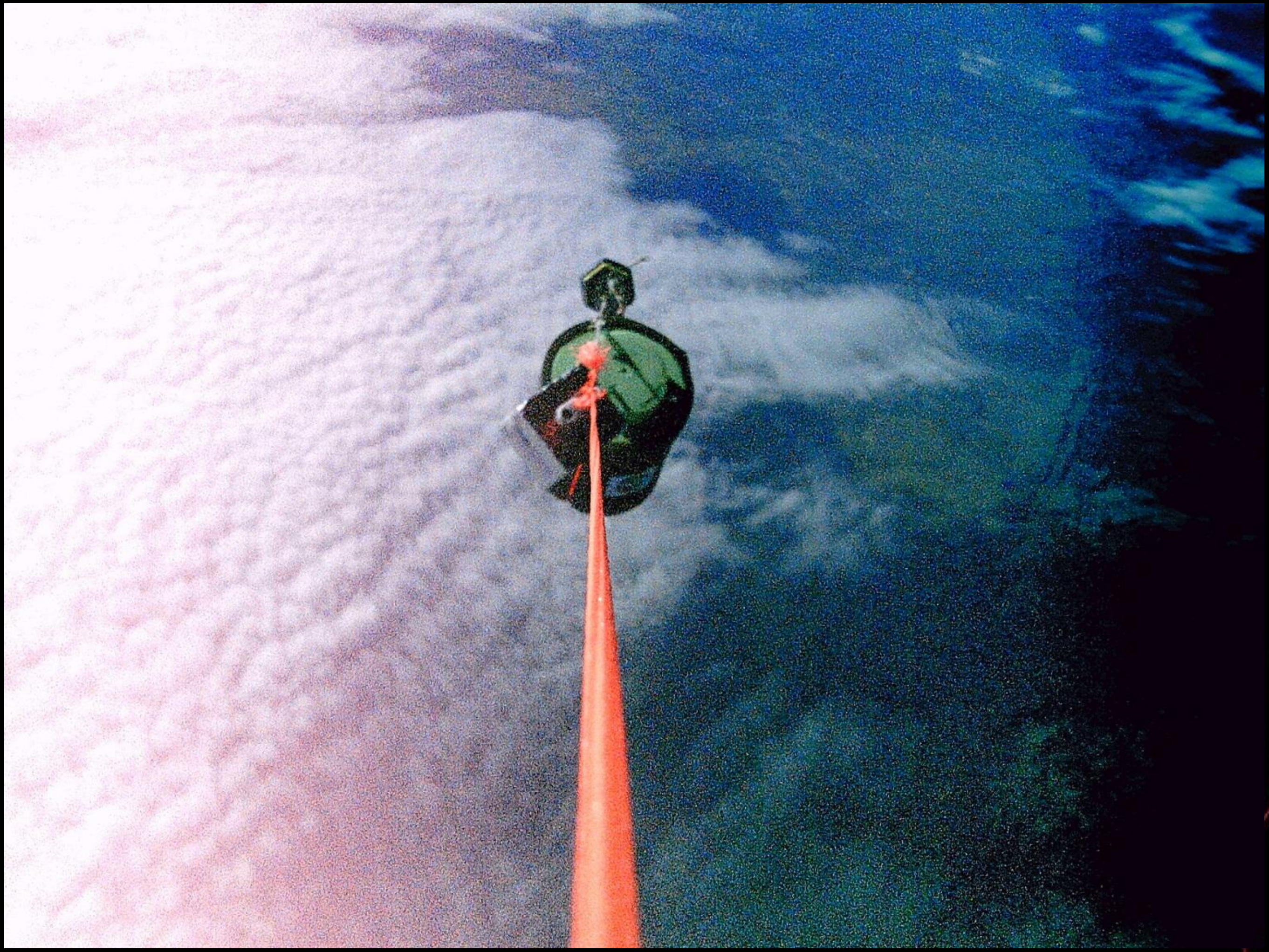

Current Time
Orbit Propagator: SGP4
Most Recent TLE
Commanded Orientation (Body to Orbit Frame)
+
+
Commanded Orientation (Body to ECI)
Clock
Orbital Position (ECI)
Quaternion relating Body to ECI
[q_1 q_2 q_3 q_4]
Current Time
Sun Ephemeris Calculation
Sun position (ECI)
+
+
Sun Vector (ECI)
Determination Algorithm: Kalman Filter
Control Logic: PD Controller
Orbital Position (ECI)
IGRF Lookup Table
Magnetic Field Vector (ECI)
Body Rates
[ω_1 ω_2 ω_3]
Commanded Body Torques
[T_1 T_2 T_3]
Sun Vectors (Mounting Frame)
Sun Vectors (Body Frame)
Sun Sensor
Individual Sensor Calibration & Coordinate Transformation: Mounting to Body Frame
Magnetorquer
Command Current Pulses
Calculate Current Pulses to Magnetorquers & Wheel Speed Commands
Magnetic Field Vectors (Mounting Frame)
Magnetic Field Vectors (Body Frame)
Magnetometer
Sinclair Wheel
Command Voltage
PolySat

Camera and Derivative Imaging

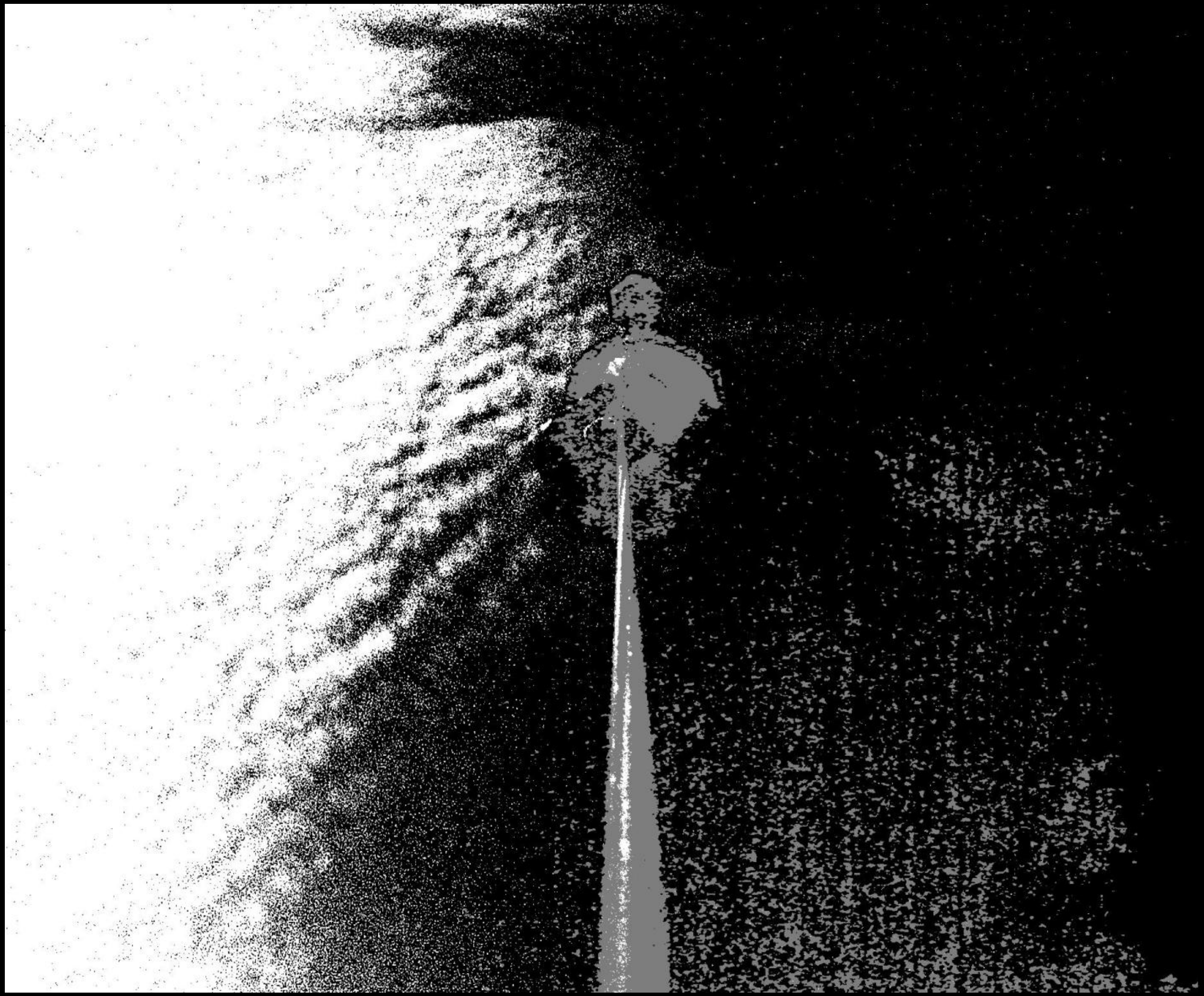
- Use camera to verify boom deployment and achieved pointing requirement
- Incorporate derivative imaging to minimize data download
- Can use derivative images to calculate rates and changes in orientation
  - Find consistent points on two images, calculate the change



Camera Test: CP8 Balloon Launch



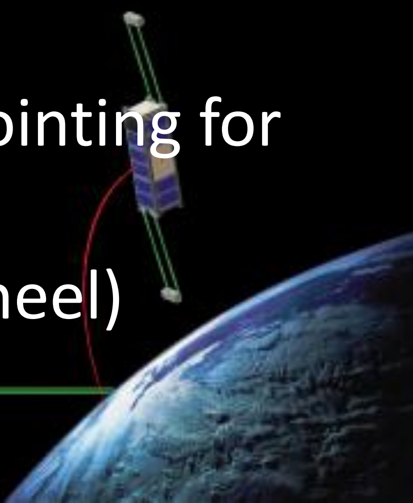
Derivative Imaging



- Picture dimensions the same
- Original Size: 1.85 MB
- New Size: 625 Kb

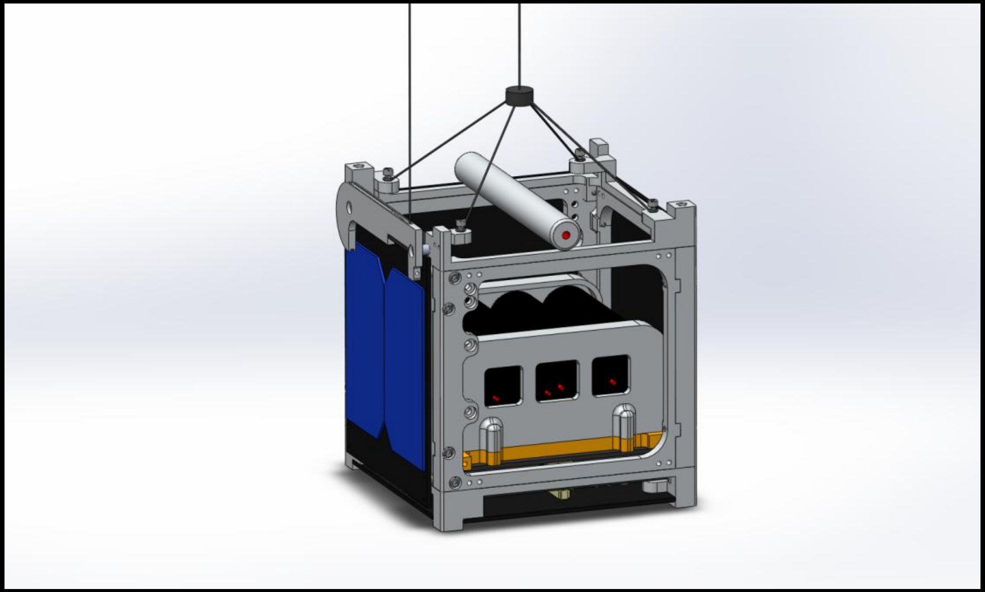
ADCS Con Ops

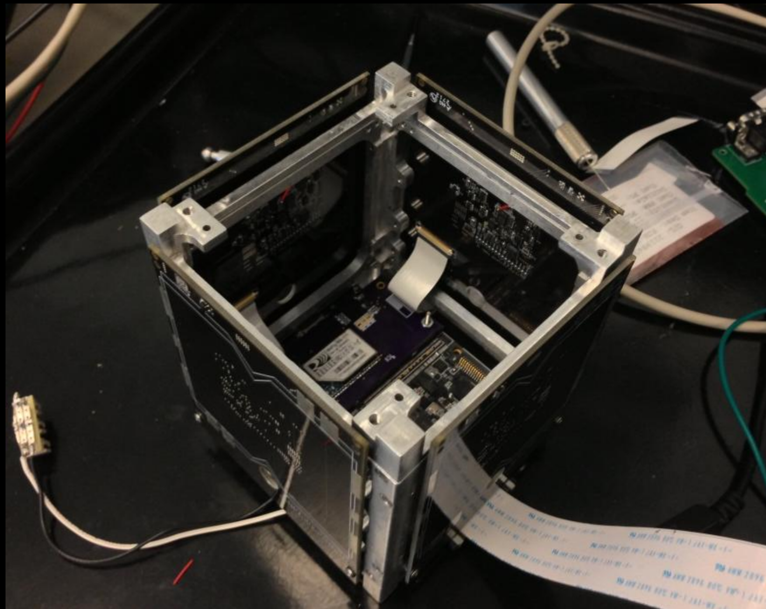
- Detumble using B-dot | verify rates using gyroscope
- Deploy booms | verify boom deployment with camera
- Activate Kalman Filter and PD controller | acquire initial pointing
- Spin up momentum wheel | continue to torque to maintain marginal stability
- Reacquire once wheel is at speed
- Verification of pointing through camera
- Turn off control system, monitor for loss of pointing for at least two orbits
- Turn on payload, turn off ADCS (except for wheel)



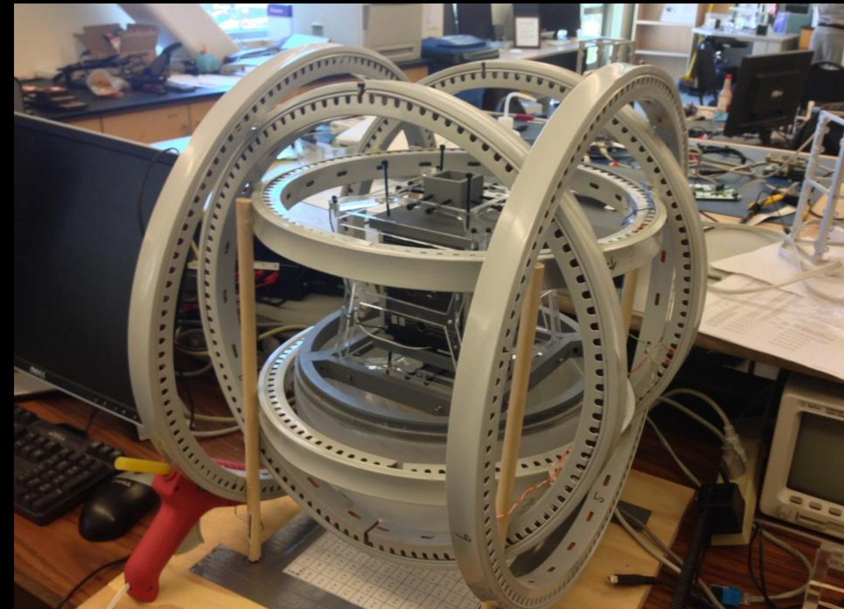
ADCS Hardware Testing: 1U Test Cube

- Integrate ADCS software into system board with sensors, actuators, communications, and camera
- Hang it from the ceiling and perform one-axis control (linear control law)
- Using external camera to verify functionality





1U Test Cube



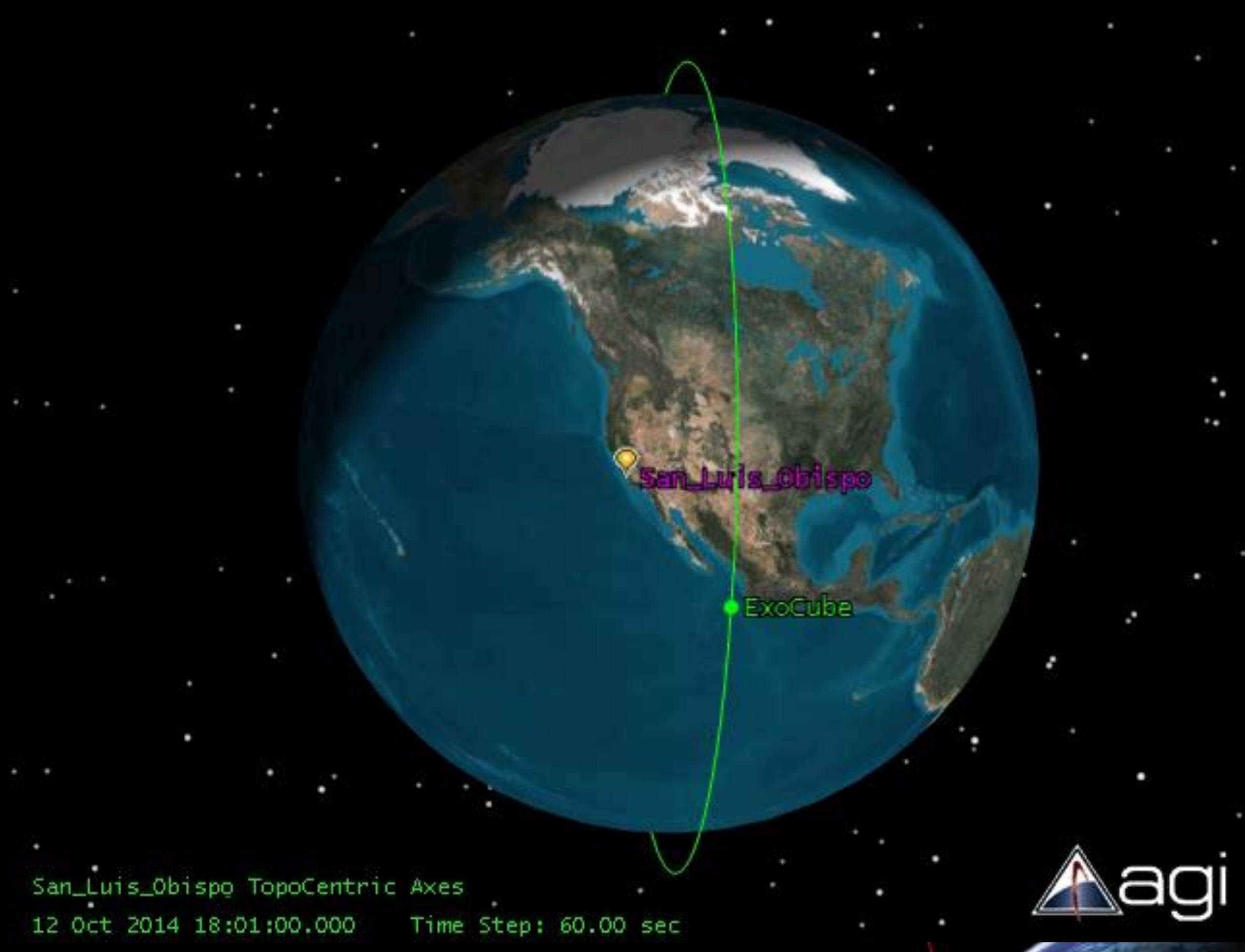
Calibrating Panels

This procedure allows us to:

- Calibrate and test all sensors and actuators together
- Write all software for ADCS and test easily with sensors and actuators (Easy hardware in the loop)
- Verify all hardware is working together properly
- Calibrate Kalman Filter based on actual hardware
  - Can create very accurate noise and measurement matrices

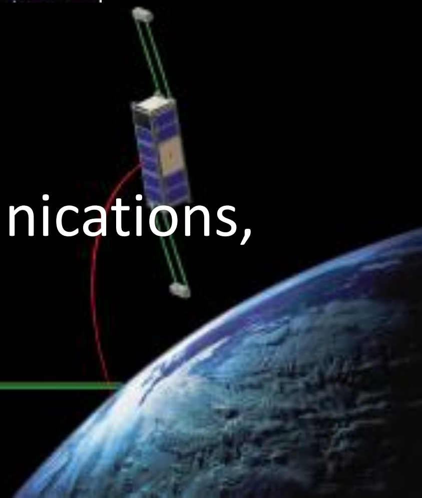
Orbit Analysis

- 400 x 670 km altitude
- 98 degree inclination
- Orbit decay projected at 8 years (4 kg mass)
- Slight eccentricity disrupts gravity gradient (.0197)

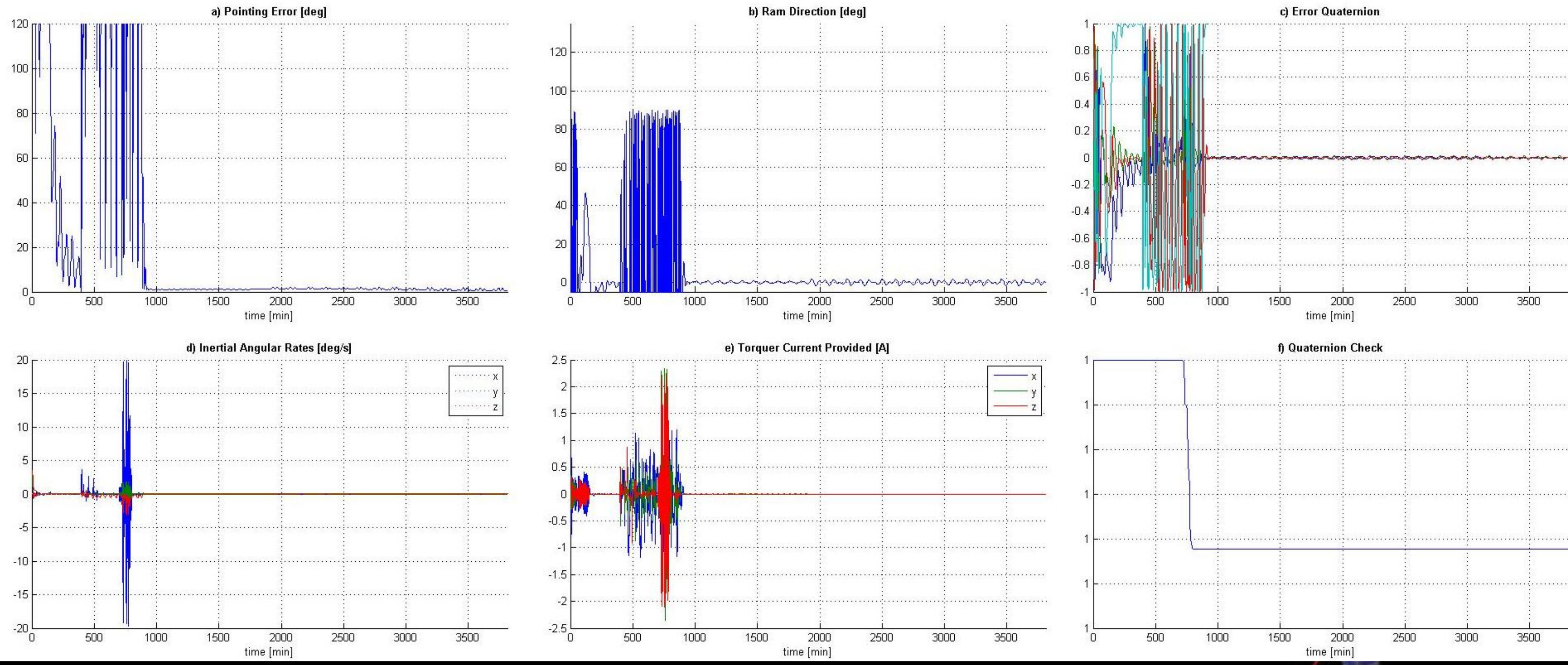


Ground Tracks

- Passes over San Luis Obispo every 8 orbits
  - Approximately 12.8 hours
  - Good for synching clock, reloading TLEs, communications, downloading images

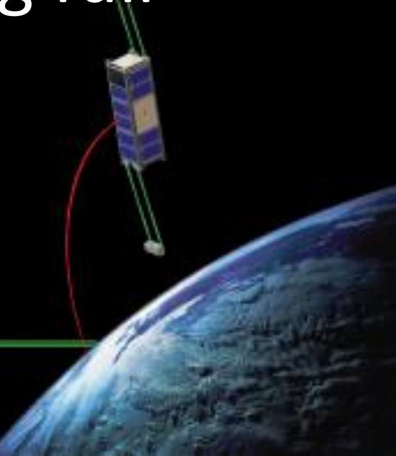


Simulation Results: 40 Orbits

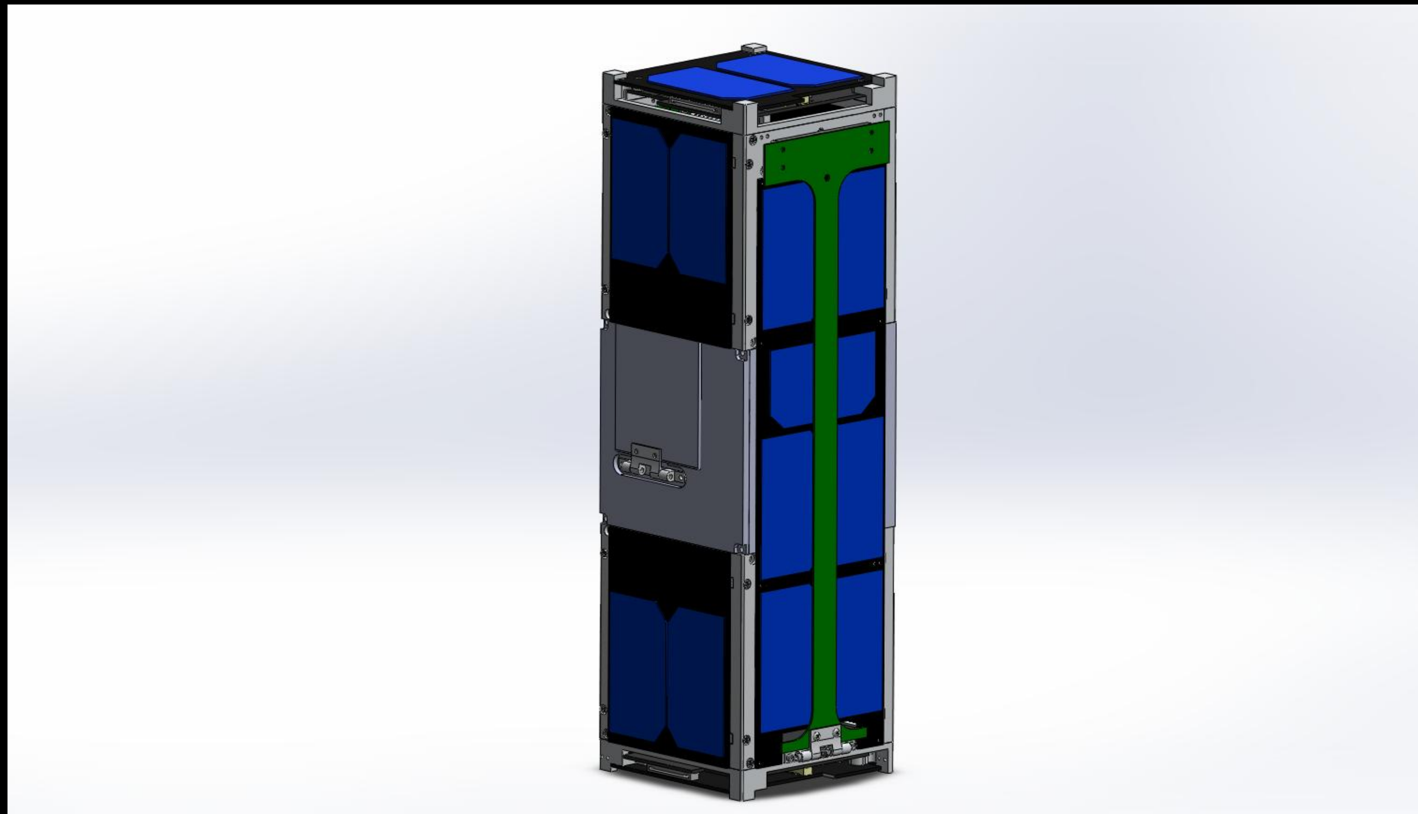


Next Steps:

- Fine tune the Kalman Filter
- Explore options for dampening pointing drift
  - Changing the constant speed of the momentum wheel
  - Changing tip masses of booms
- More detailed Con Ops based on orbital position
- Continue hardware testing and integrating full ADCS



PolySat



Questions?