



# An Open-Source Reaction Wheel System for Oregon's First Satellite

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## $\mu$ -gravity Controls Testing

- Bode analysis of cube dynamics in “space-like” free-fall environment
- Portland State University’s Dryden Drop Tower facility can access a  $1 \times 10^{-5}$  to  $10^{-6}$ -g environment for 2.1 s
- Cube damps roll following a random (25% duty cycle PWM) perturbing impulse



Figure: Portland State University’s Dryden Drop Tower (Credit: Andrew Wollman)

## OreSat

- Mission: STEM outreach by sending live video space-to-ground to tracking stations built and operated by Oregon high schools
- Ground stations will be built using 3D printers, COTS WiFi adapter cards, and existing augmented reality cellphone apps that track satellites
- S-band downlink at approximately 15 dBi gain. Needs to “point-and-stare” at ground stations with **5-10° of pointing at 1 deg/s of slew**
- Will use a **reaction wheel** based system to provide attitude control



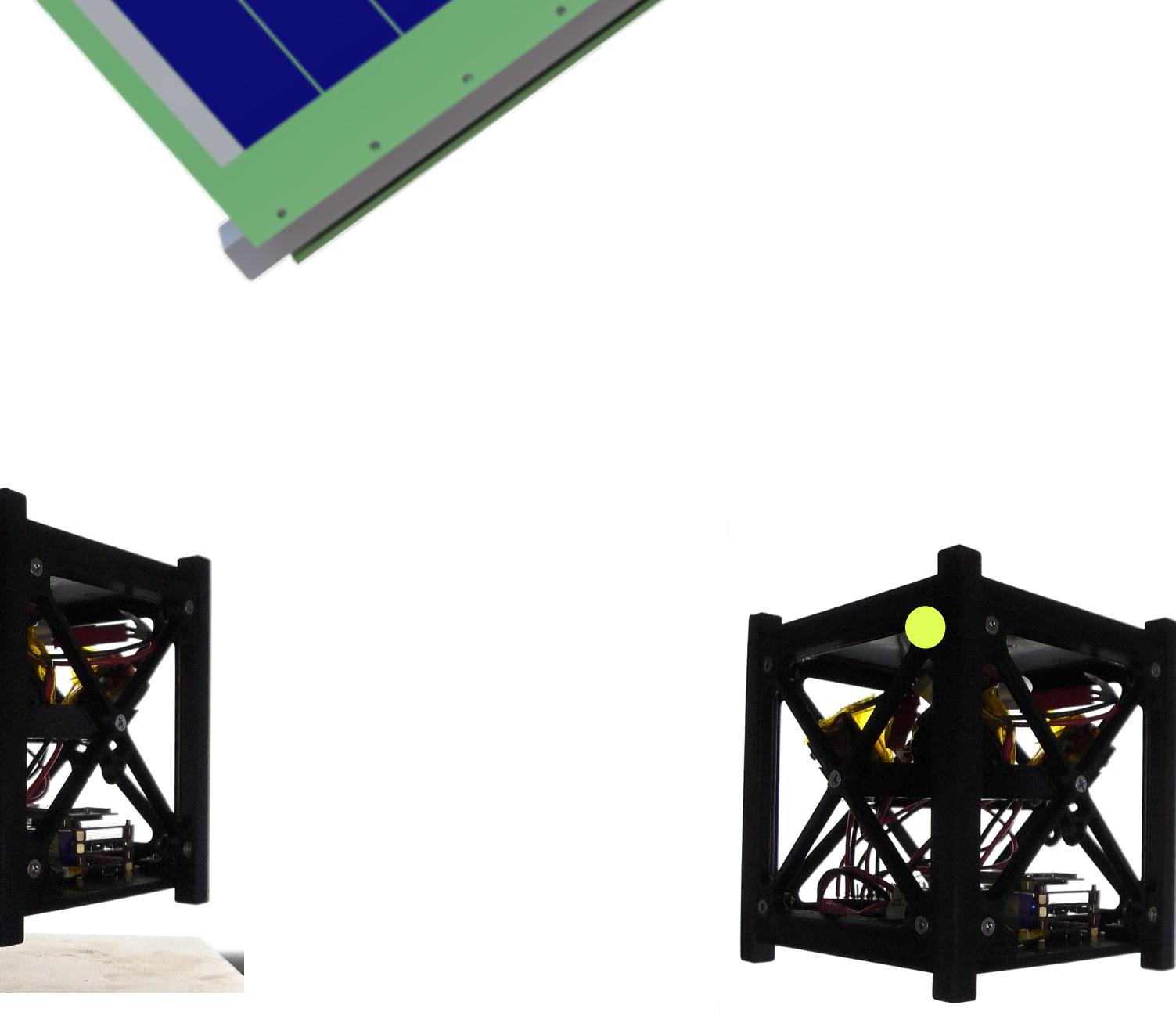
## Controls Development

- The controller for the reaction wheel system is a simple PID loop
- The top-level controller design procedure was as follows:
  - Determine the transfer functions from dynamics analysis of free body diagrams of the system
  - Create simulation in GNU Octave
  - Design the controller using iterative testing (with comparisons to the model) and classical Bode techniques
- The forces acting on the cube are the torques created by the motors  $T_i^0$ , damping effects  $b_i\dot{\theta}_{cube}$ , and spring effects  $G_i\theta_{cube}$ . Summing the moments around the center of gravity gives the following equation (for the x-axis):

$$M_0^+ = I_{x,cube}\ddot{\theta}_{x,cube} = T_{Ax}^0 + T_{Bx}^0 - T_{Cx}^0 - T_{Dx}^0 + T_x^0 - \dot{\theta}_{x,cube} - G_x\theta_{x,cube}.$$

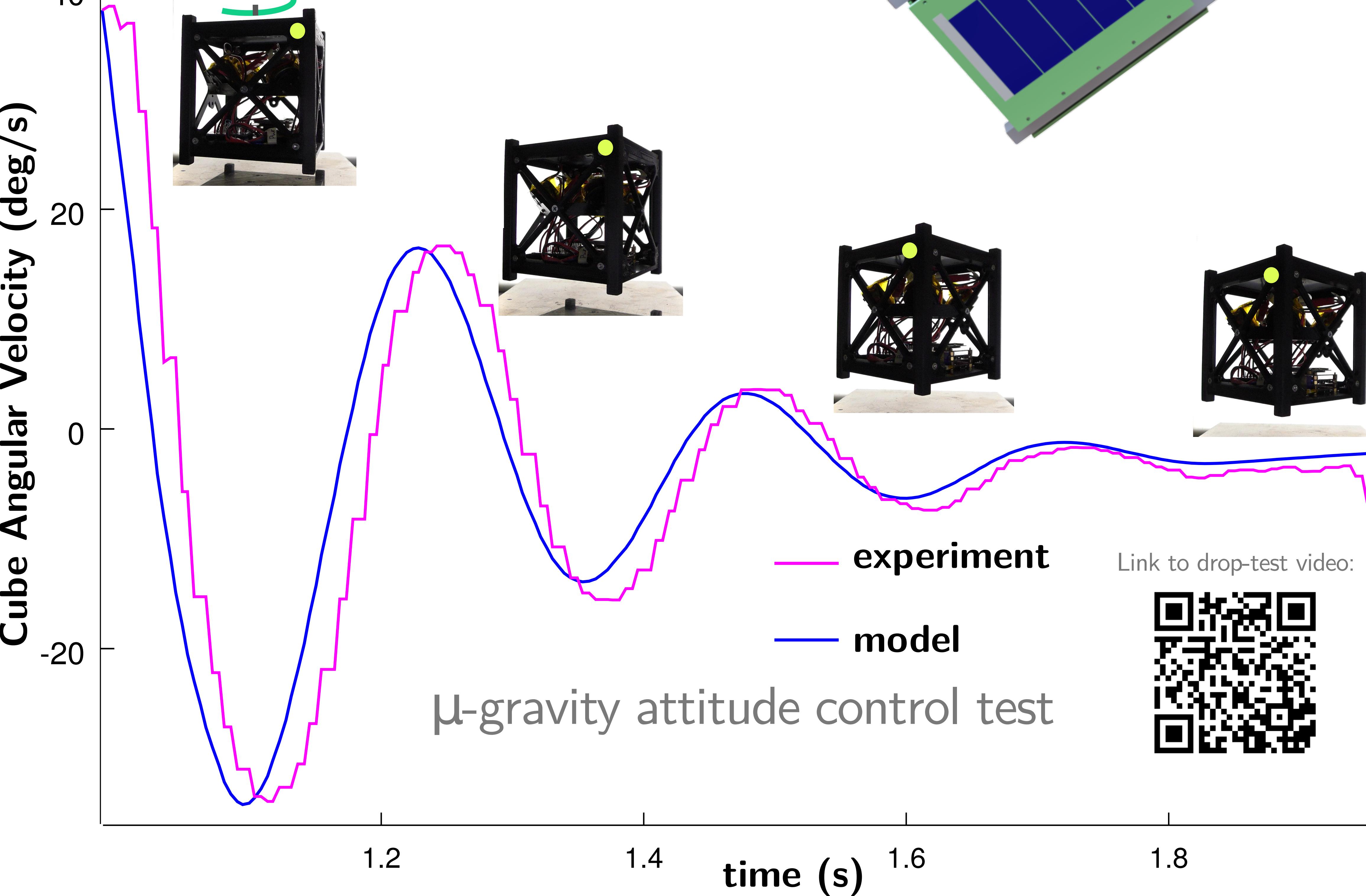
- By setting the system to Standard Equilibrium Position (at SEP the input perturbations are set to zero), considering only a single input, substituting the torque-inertia relation, and taking the Laplace transform we arrive at the (*incredibly simple*) transfer function of the cube:

$$G_A(s) = \frac{\theta_{x,cube}(s)}{\theta_A(s)} = \frac{s^2}{\frac{I_{x,cube}}{\sin(45^\circ)l_{rw}}s^2 + \frac{b_x}{\sin(45^\circ)l_{rw}}s + \frac{G_x}{\sin(45^\circ)l_{rw}}}.$$

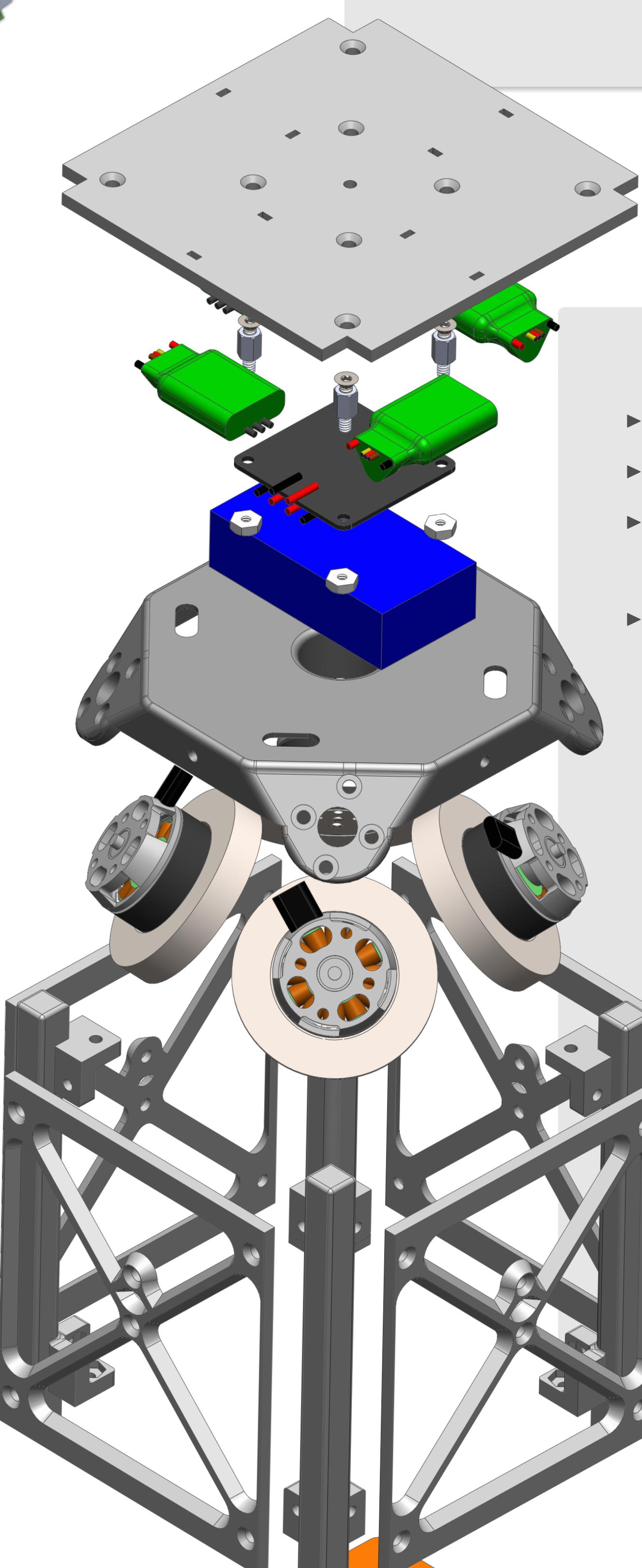


— experiment  
— model

$\mu$ -gravity attitude control test



Link to drop-test video:



## Rapid Prototyping

- Designed for rapid iteration
- FDM 3D printed main structure
- Inexpensive COTS components: DC Brushless hobby motors, Intel Edison microcontroller, and Sparkfun “blocks”
- Controller code written in Python

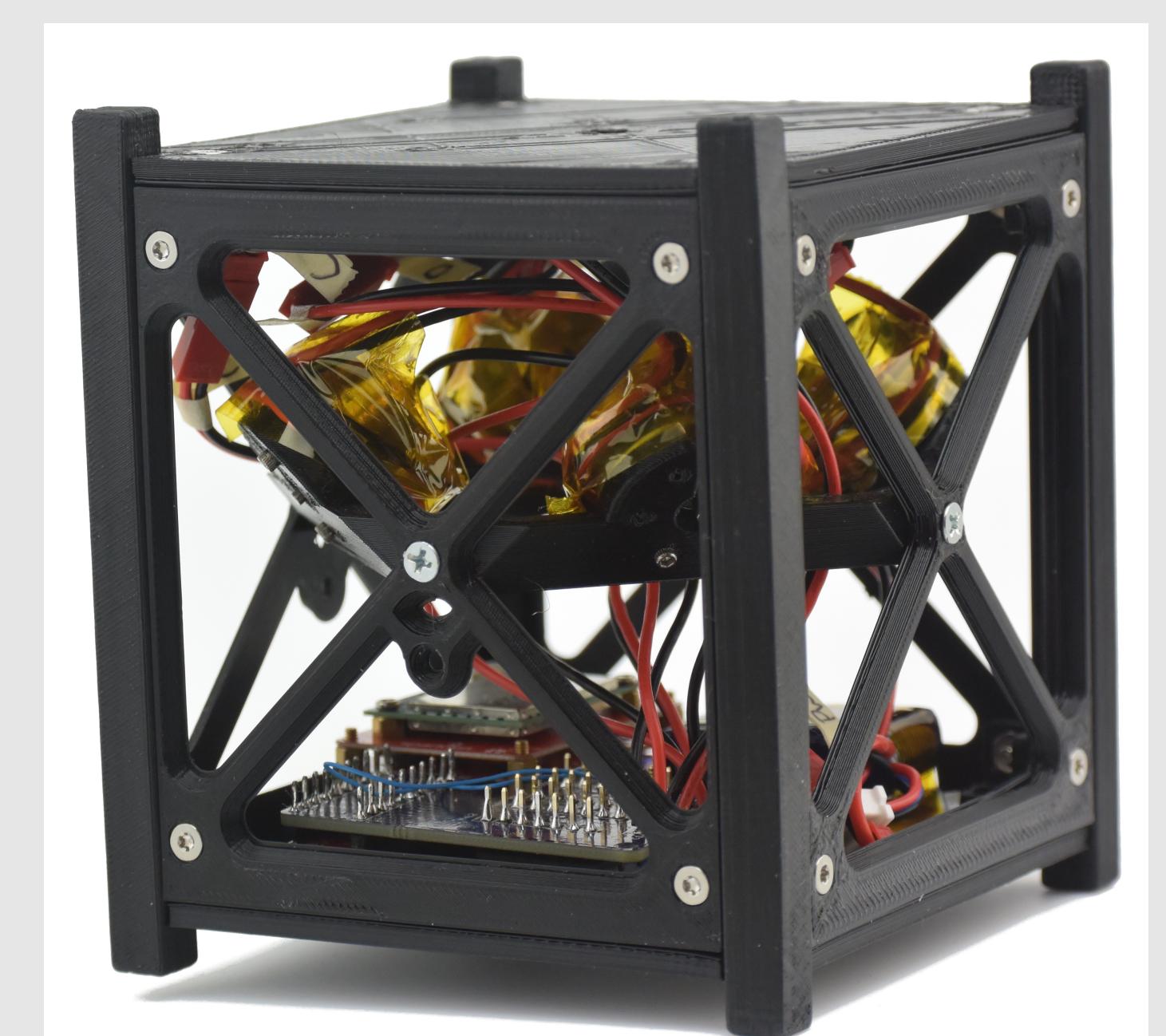


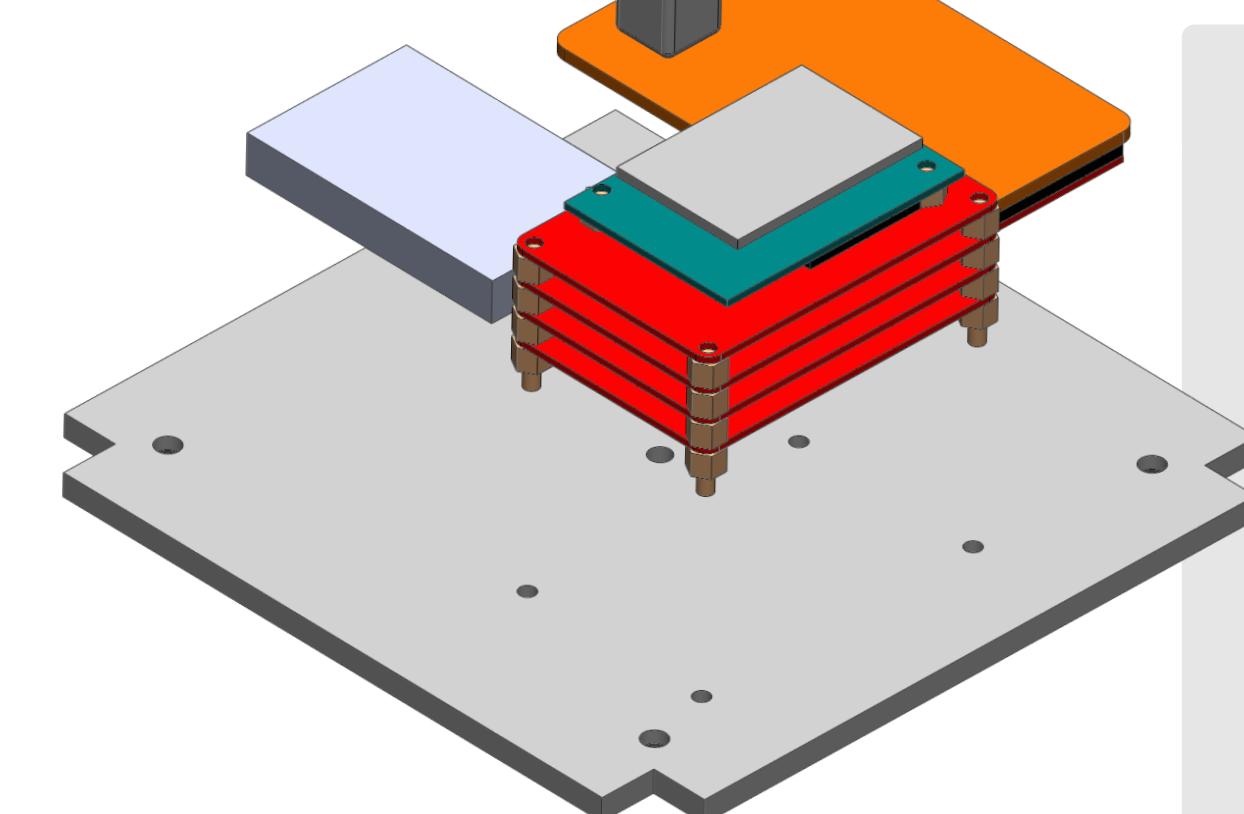
Figure: The reaction wheel subsystem test cube.

## Open-Source

- Project deliverables freely and publicly available under a GNU GPL v2 license
- <https://github.com/oresat>

## Further Work

- Need more drop-tests: complete Bode diagram to improve dynamical model, further controller design iterations
- State determination with sensor fusion via Kalman filtering suntracker, magnetometer, and gyroscopes



## References

- Mahoney, Erin. *CubeSat Launch Initiative: 50 CubeSats from 50 States in 5 Years*. NASA, April 9, 2015. <http://www.nasa.gov/content/cubesat-launch-initiative-50-cubesats-from-50-states-in-5-years>.
- The CubeSat Program, Cal Poly SLO. *CubeSat Design Specification Rev. 13*. San Luis Obispo: California Polytechnic State University; 2014.