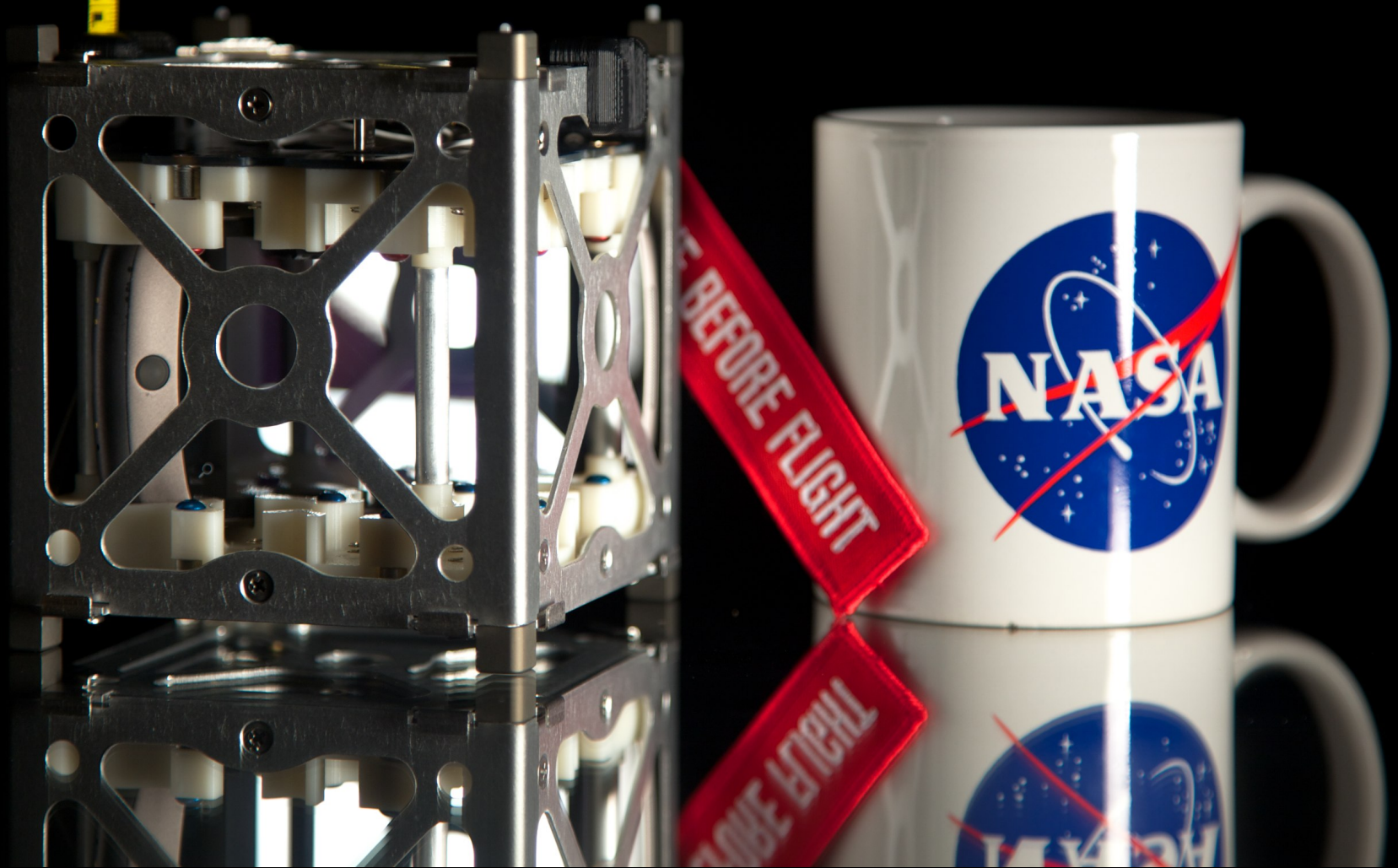


# 9<sup>th</sup> Annual Spring Cubesat Developers Workshop Cal Poly San Luis Obispo

## PhoneSat 2.0

V. Beukelaers, C. Boshuizen, A. Guillen, B. Howard, W.  
Marshall, M. Safyan, O. Tintore, E. Agasid  
NASA Ames Research Center  
Universities Space Research Association

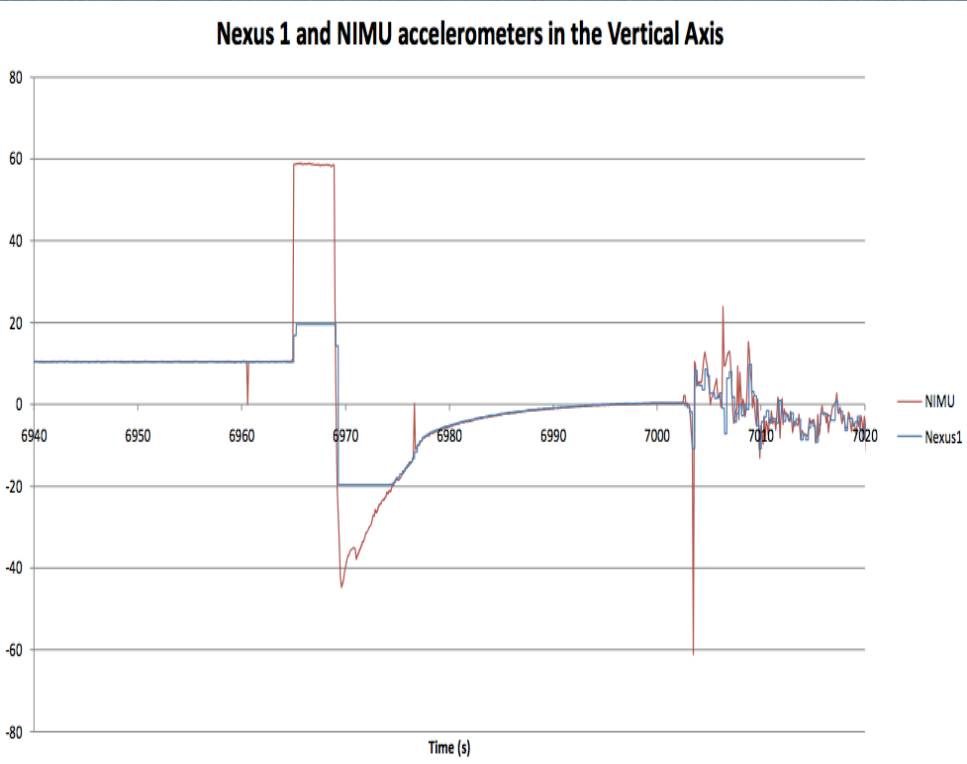
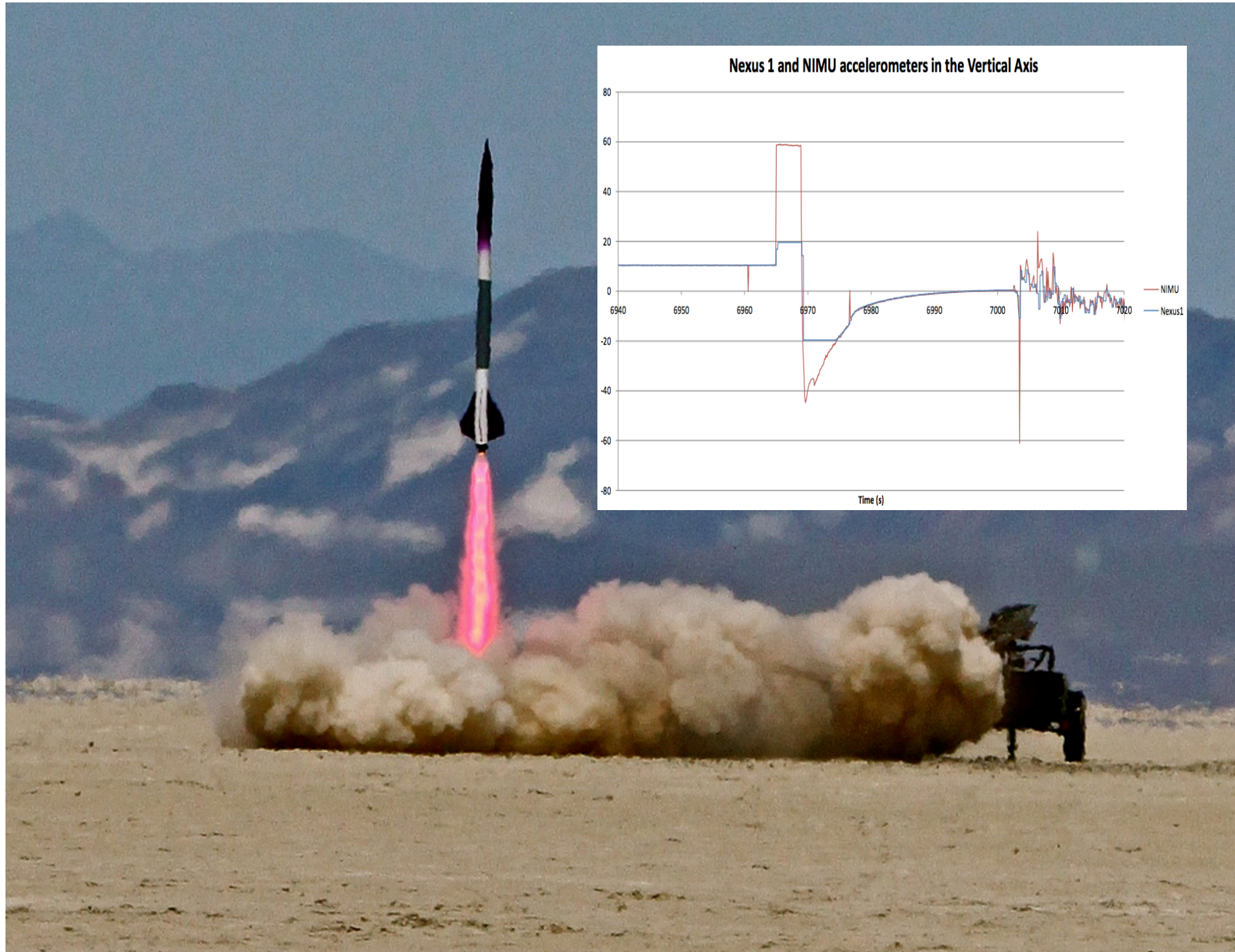
# PhoneSat 1.0





# Why use a phone?

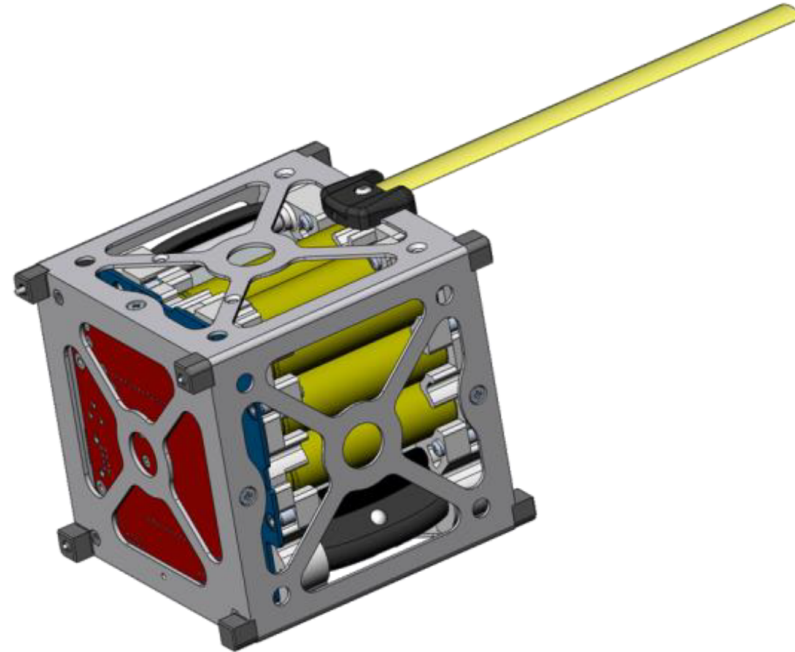
- Increase on-orbit processor capability by a factor of 10-100
- Decrease cost by a factor of 10-1000
- Free up cubesat volume for additional payload through avionics miniaturization
- Demonstrate COTS approaches to all subsystems (ie, power, ADCS, comms)
- ➔ Produce high-capability spacecraft for \$1-10k (exc. LV)





# Phonesat VS1

- 1U cube
- Entire phone
- Batteries
- Watchdog board
- Stensat radio



- Main goal: test phone is viable solution





# Phonesat VS2

## New Features

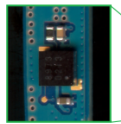
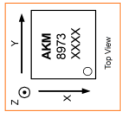
- Solar panels
- Reaction wheels
- Magnetorquers
- 2 way radio ( $\mu$ Hard 2420)
- Nexus S



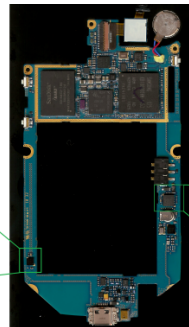
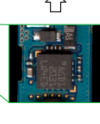
# ADCS block diagram

## SENSORS

Magnetometer



Gyroscope



Coarse Sun Sensor



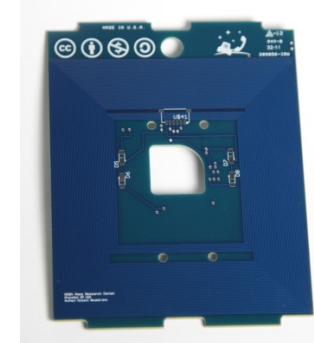
## ADCS COMPUTER



Phone

## ACTUATORS

Magnetorquers



Reaction wheels

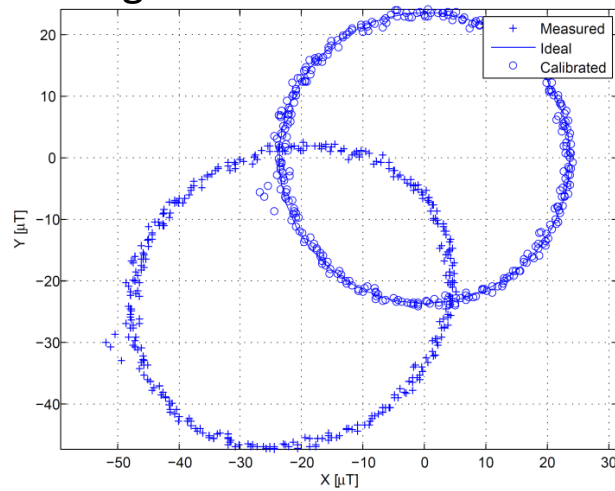






# Sensor tests

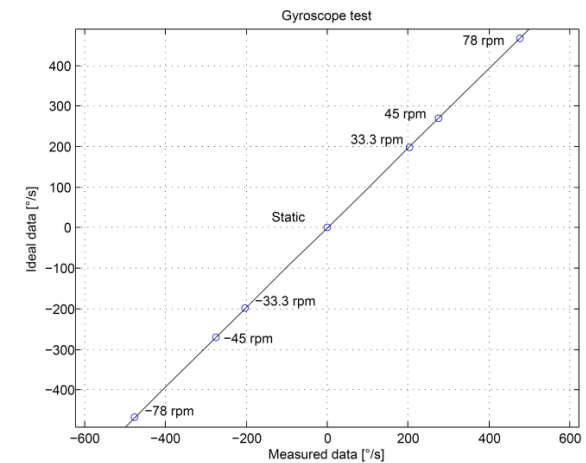
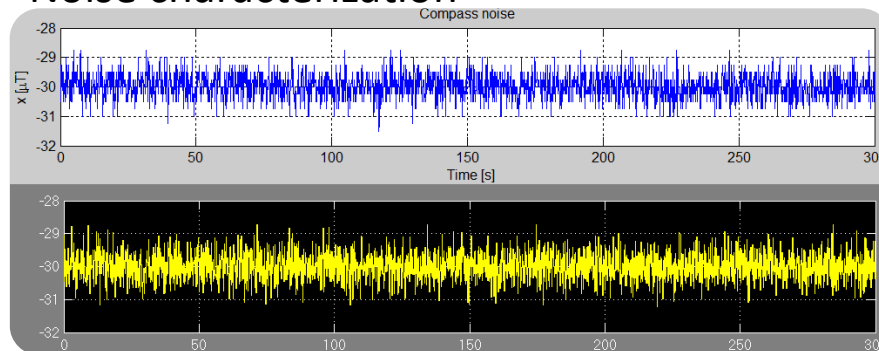
## Magnetometer calibration



## Gyroscope calibration



## Noise characterization



- Interferences when GSM antenna removed
  - Solution: Turn on airplane mode!



# Solar panels

## Space-qualified cells



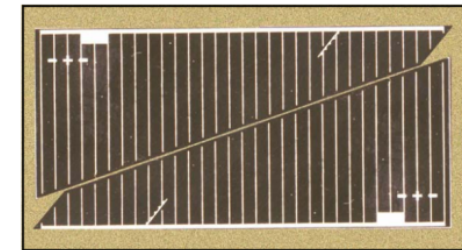
- Efficiency: 27-30%
- Expensive  
Long lead time

## Portable smartphone chargers



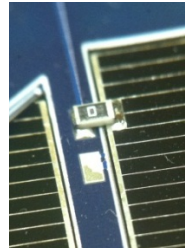
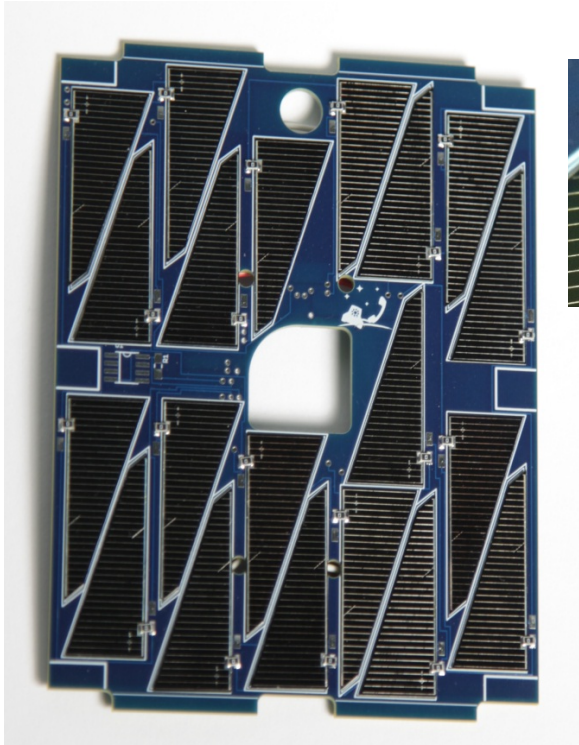
- Cheap  
Easy assembly
- Efficiency: 14%

## TASC cells



- Cheap: \$2.5/cell  
Efficiency: 27%
- Handling (brittle)  
Mounting process
  - Double-sided Kapton tape
  - Conductive epoxy
  - RTV coating
  - ...

# Pick-n-Place solution

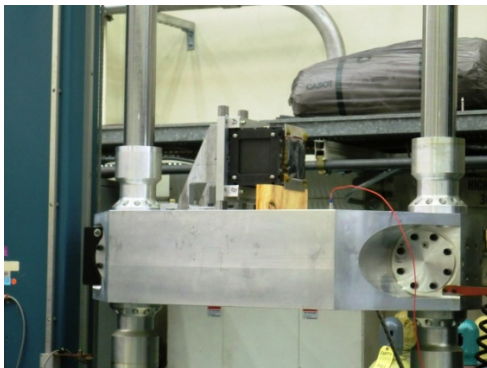


- Use Pick-n-Place machine
- Treat cell as SMT component

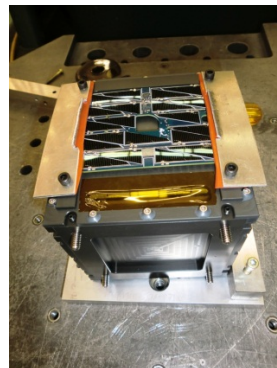
## RESULTS

- \$150/panel
- Integrated magnetorquer
- 2 weeks
- Reliable quality
- Great accuracy
- No coverglass

Shock (NASA GEVS)



Vibe (NASA GEVS)



Vacuum



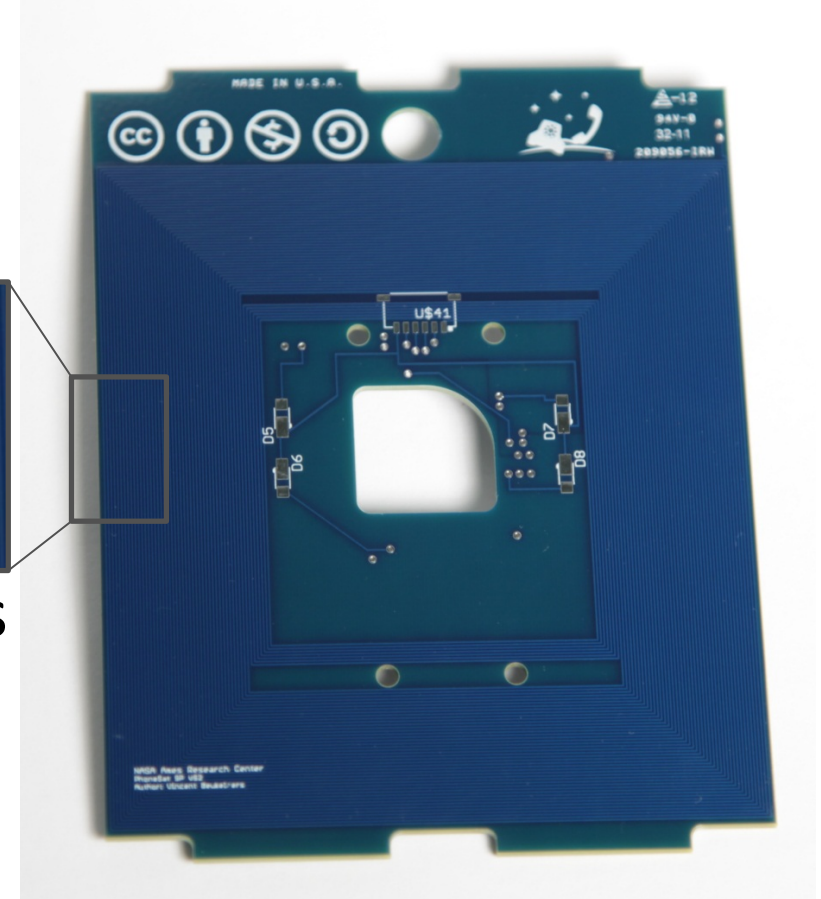
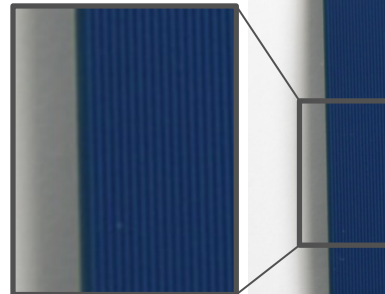
Thermal cycling





# PCB-integrated magnetorquers

- 6-layer PCB
- 5 layers of coil & 1 layer of solar cells
- 50 turns per layer
- Magnetic moment:  $30 \text{ mA}\cdot\text{m}^2$
- Voltage: 5V
- 100mW per axis
- Temperature sensor
- Integrated reverse-bias diodes



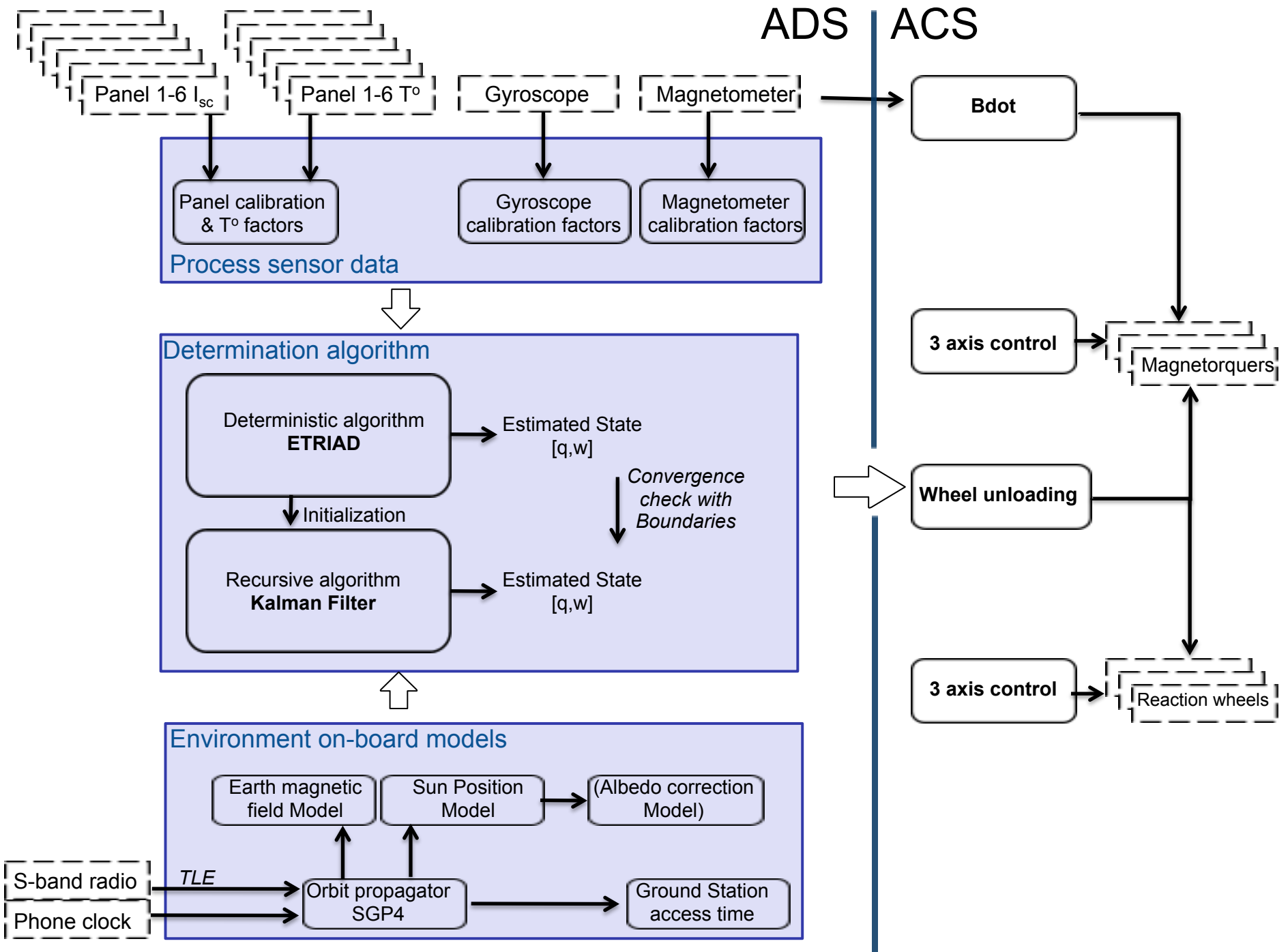


# COTS reaction wheels

- Brushless DC motor
- Angular momentum (@7000rpm):  $5.9e-4$  Nms
- Maximum speed: 7000 rpm
- Inertia:  $8.1e-7$  kg.m<sup>2</sup>
- Integrated speed controller
- Hall effect sensors
- Mass: 20g
- 26x26x12mm<sup>3</sup>
- Operating T range: [-25 ... +80]C
- Vacuum-proofed lubricant
- Price: \$200

No extra inertia wheel needed for 1U!

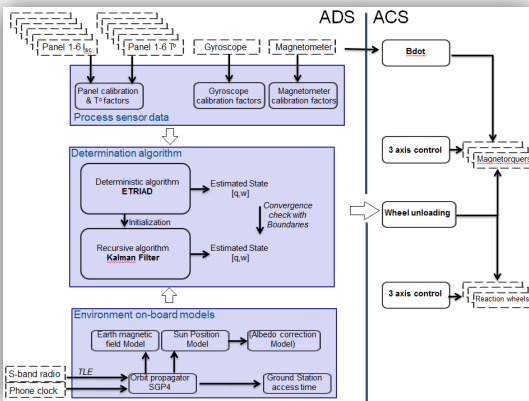






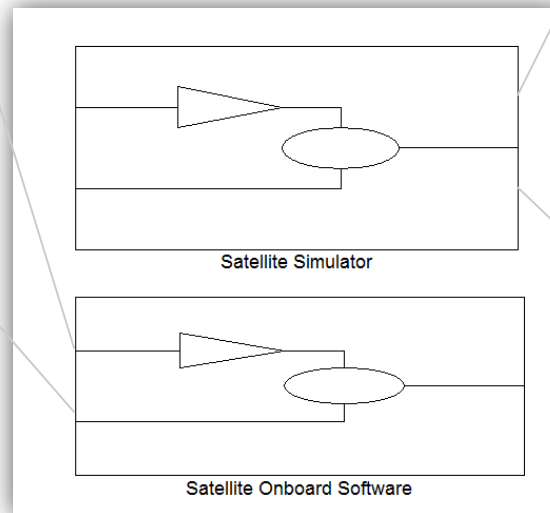
# Software-in-the-loop simulator

## ONBOARD SOFTWARE

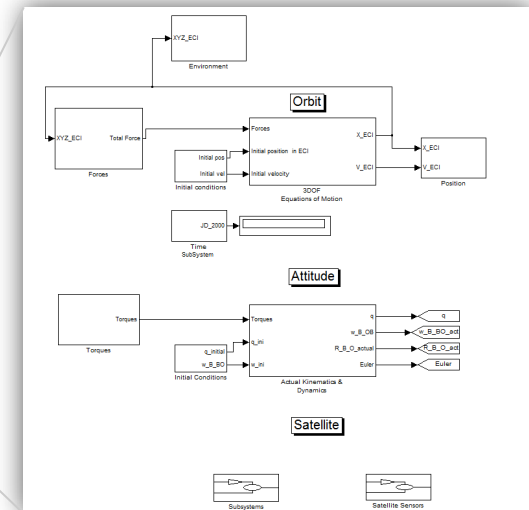


- Kalman Filter
- ETRIAD
- RW
- Magnetorquer
- ADCS modes

## SIMULINK SIL SIMULATOR



## SATELLITE SIMULATOR

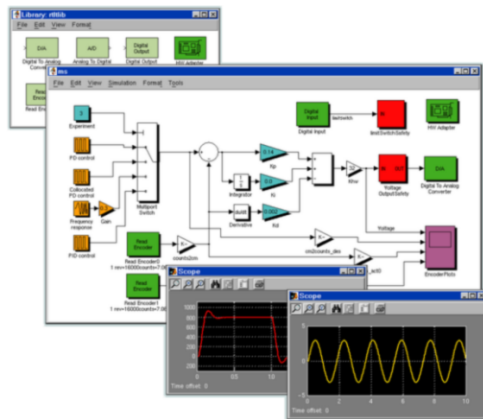


- Orbit Propagation
- Sunlight & GS Access
- S/c kinematics & dynamics
- Disturbance Torques
- Sensors emulation
- ...



# ADCS software

- Matlab/Simulink running on the phone!



Simulink Model

*Matlab  
Embedded coder*



C Code

*JNI*



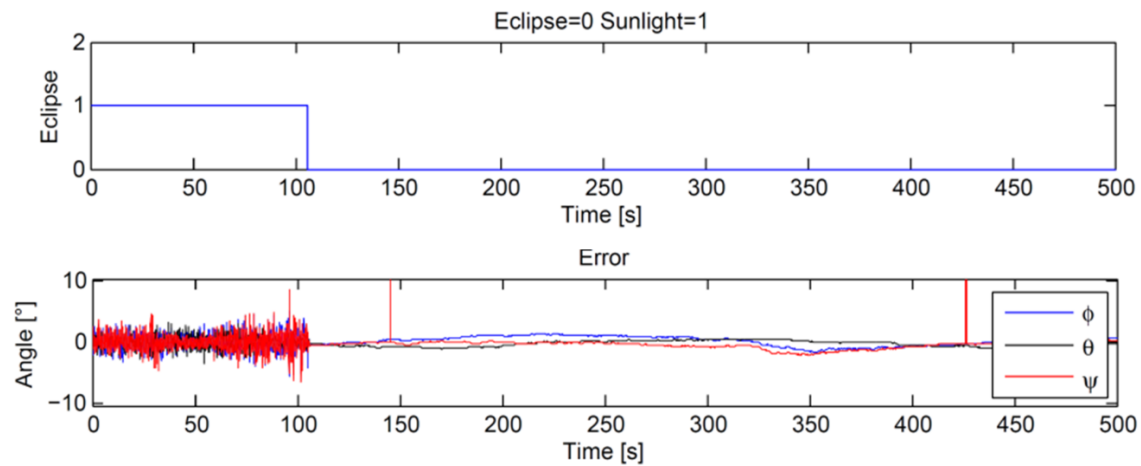
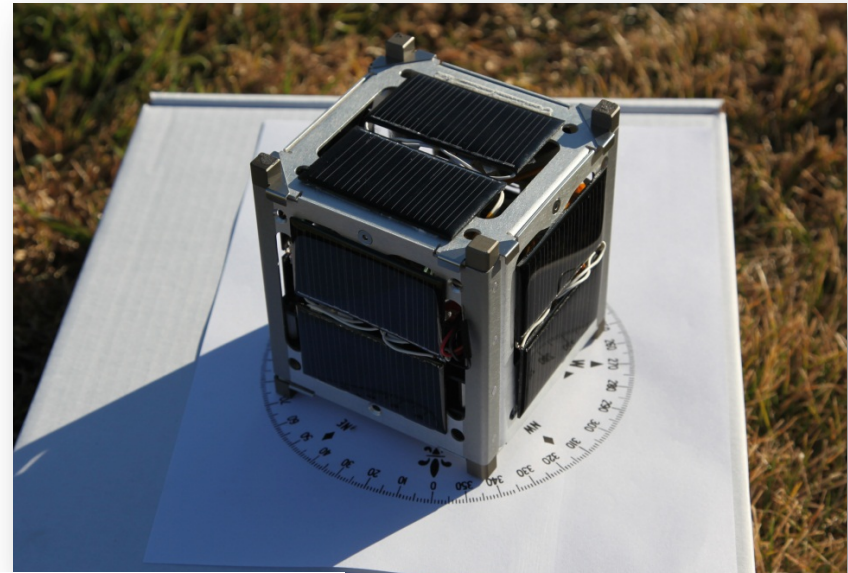
Android App





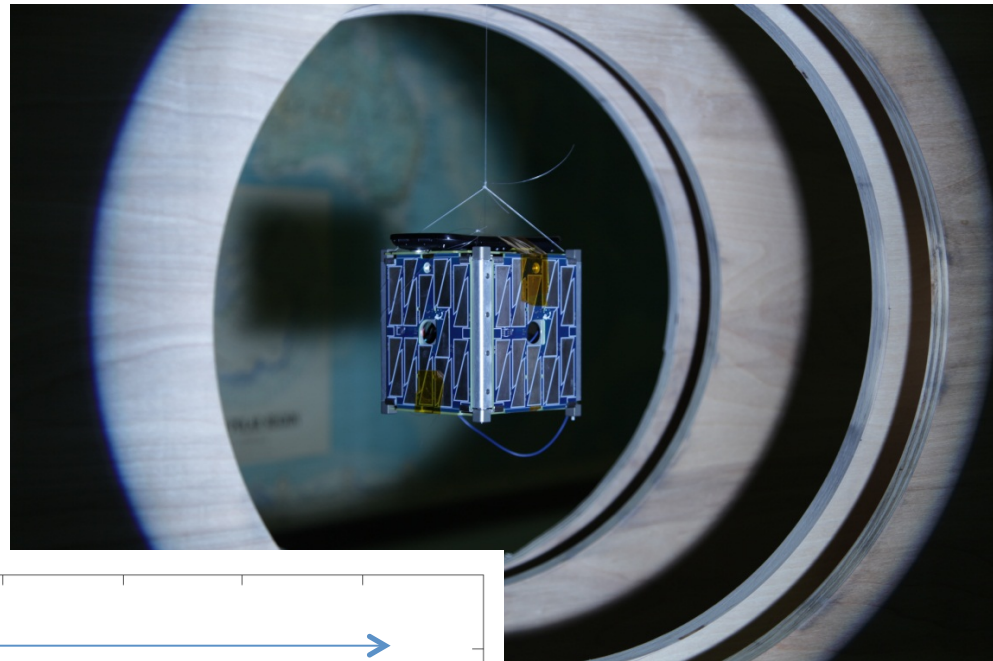
# ADS tests

- Integrated test outside
- Attitude estimation based on:
  - Magnetometer
  - Solar cells currents
- Great to debug

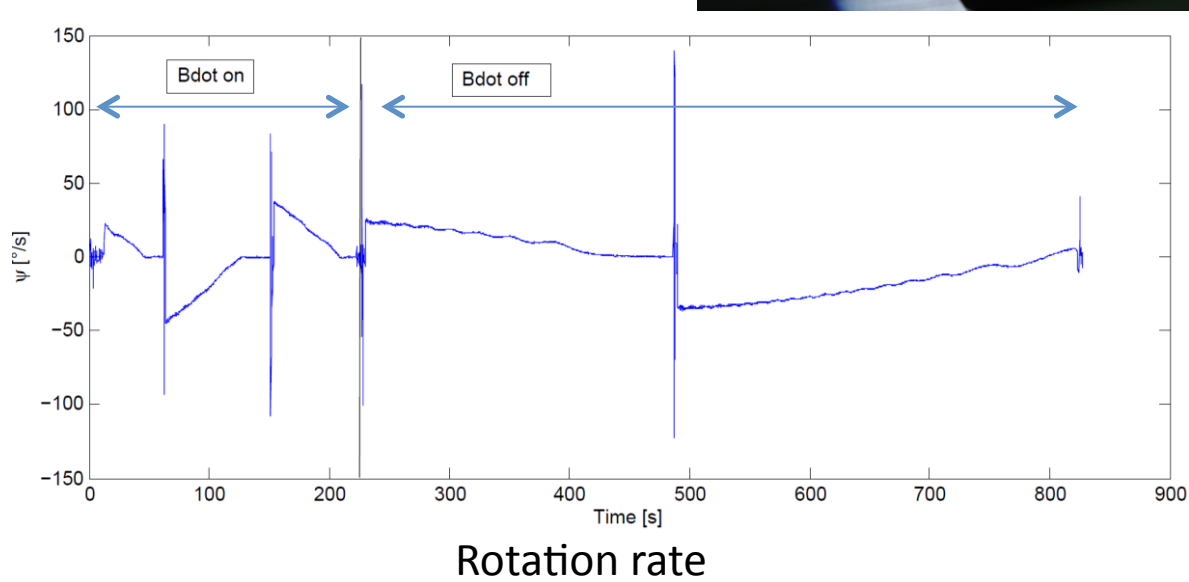




# Bdot test

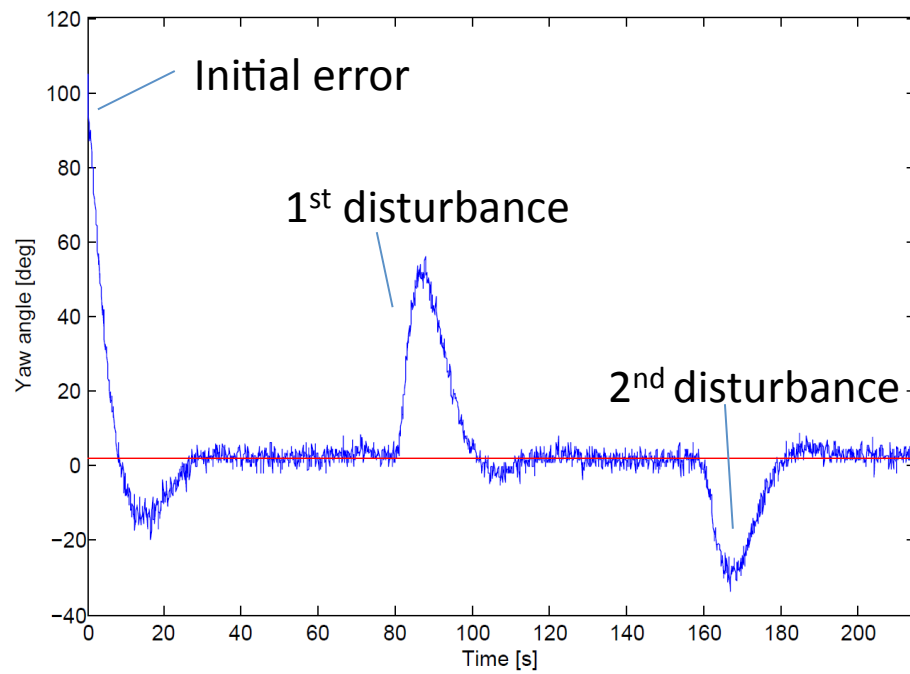


- Effectively damp rotation rate

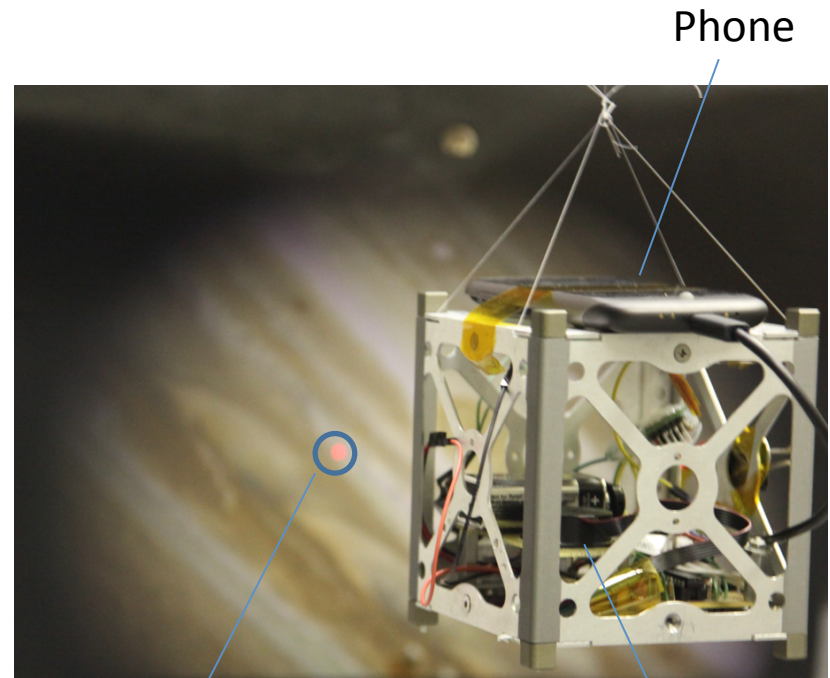




# RW test



String Test

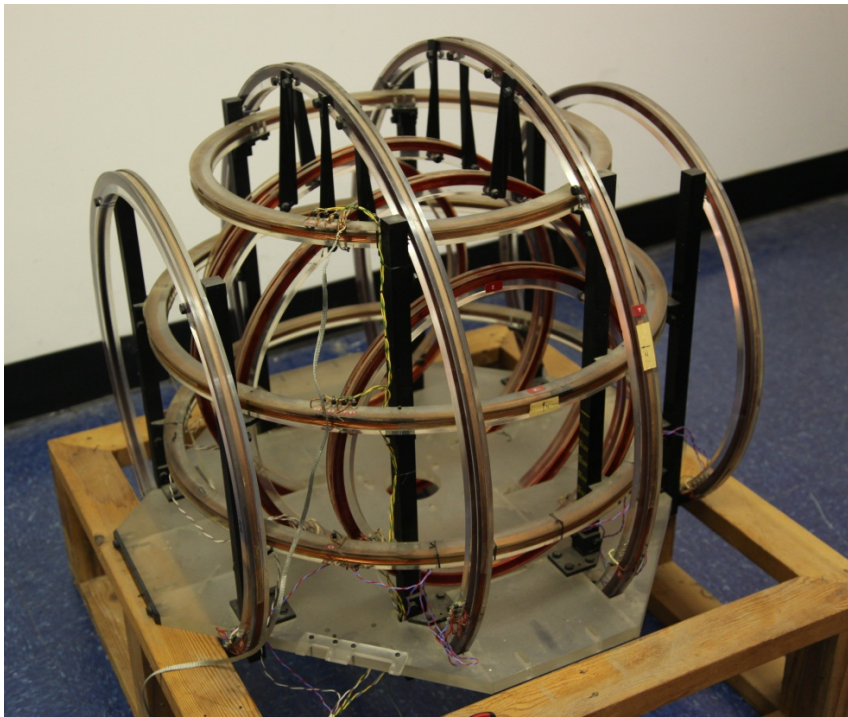


Laser pointer

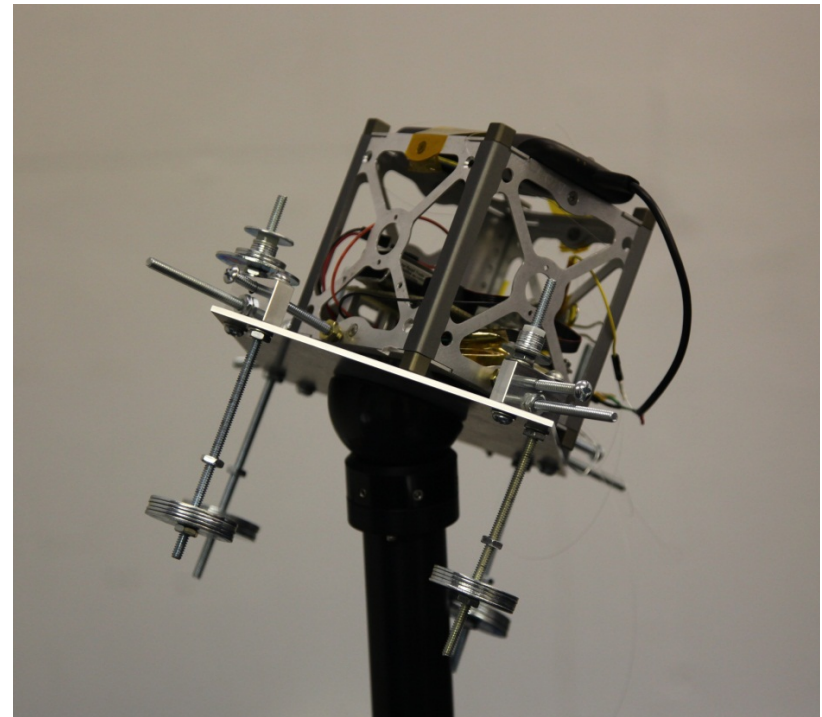
Reaction wheel



# Future tests



3-axis Helmholtz coils



Spherical air bearing



# Conclusions

- Goal: Produce high-capability spacecraft for \$1-10k
- Why? Myriad of uses to aid the agency (science, exploration, education & outreach)
- Have standard highly capable platform up there and available for people to develop apps
- Great for crowd sourcing (apps)
- Progress to date:
  - PhoneSat v. 1.0 built and ready to go!
  - PhoneSat v. 2.0 under the soldering iron!
- Launch with Taurus II (2012 Q2)
- Launch with Falcon 9 (2012 Q4)



Thank you!