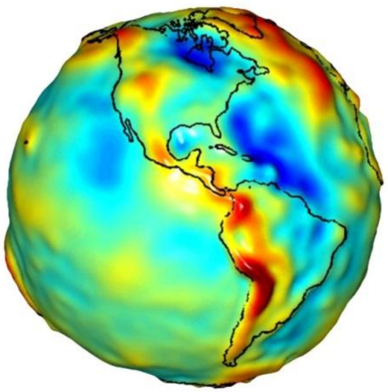

Small Satellite Constellations for Earth Geodesy and Aeronomy

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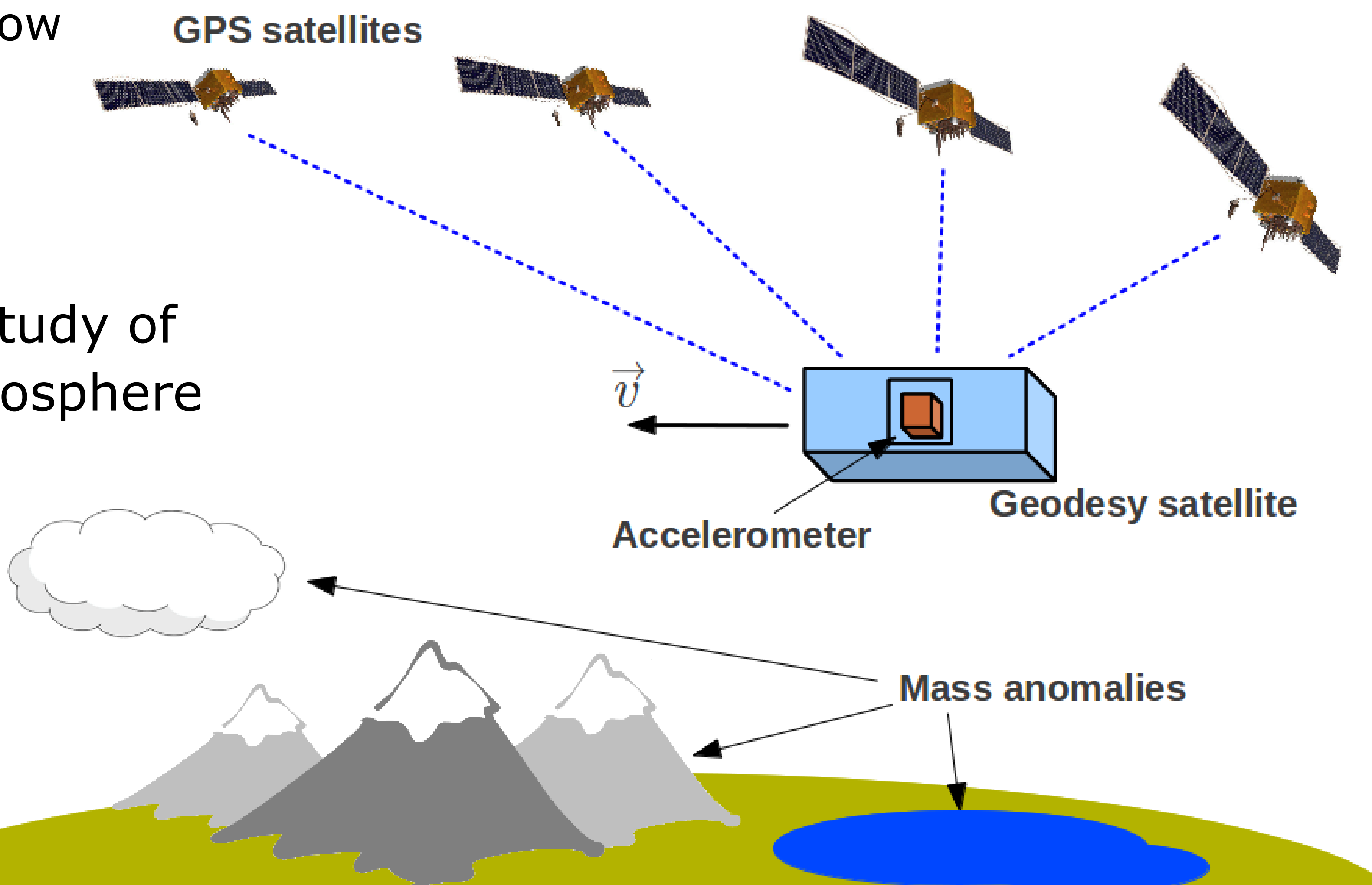
Satellite Geodesy (and Aeronomy)

- Geodesy: Measurement of the Earth’s gravitational field
- Simplest approach: 1 satellite with accelerometer + GPS
  - GPS: m accuracy, Accelerometer: 10^{-10} m/s^2 (drag ~ 10^{-6} m/s^2)
  - AKA: High-Low
  - Ex: CHAMP (2000)

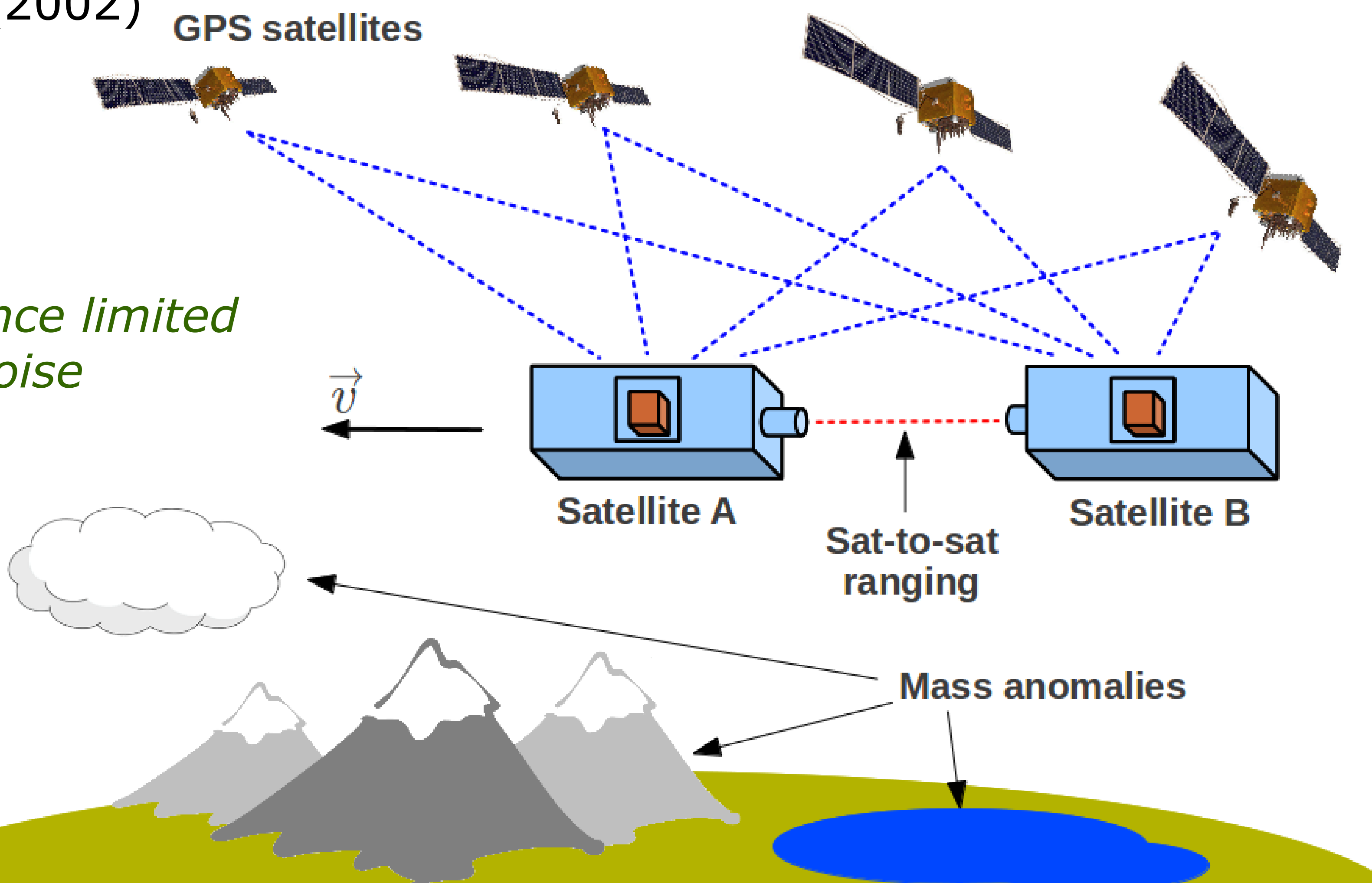


- Aeronomy: Study of the upper atmosphere

A Differential Measurement

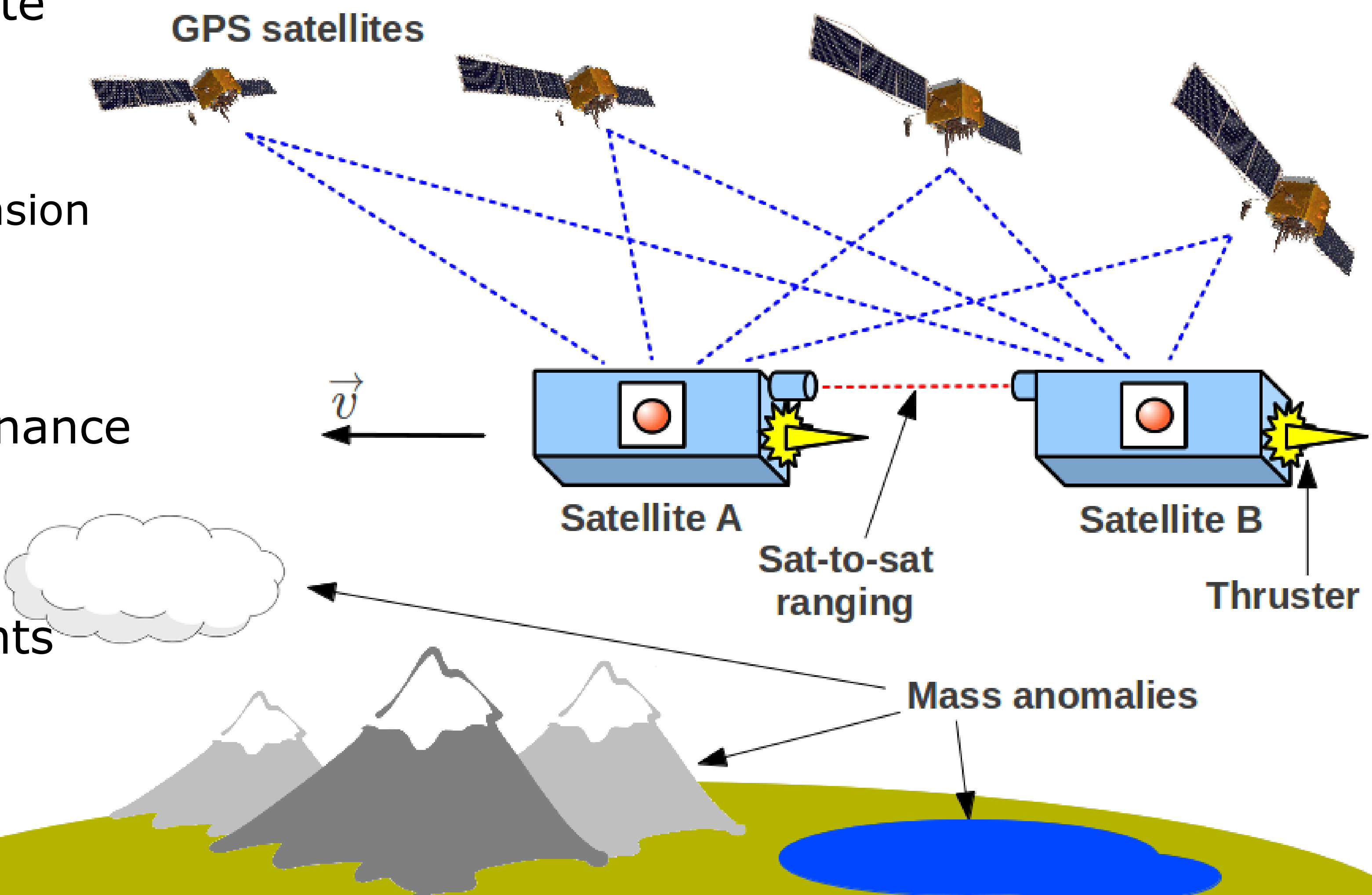
- Differential approach: 2 satellites w/ accelerometers, GPS, ranging
  - Ranging: μm (μ-wave), nm (laser interferometer)
  - AKA: Low-Low SST
  - Ex: GRACE (2002)

GRACE performance limited by acceleration noise



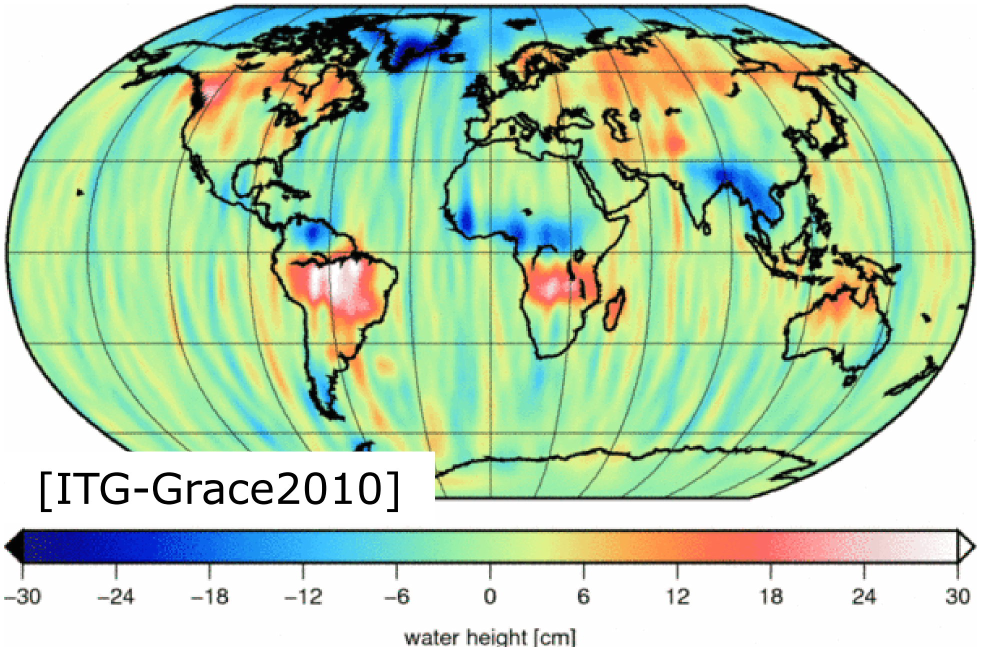
Benefits of Drag-free

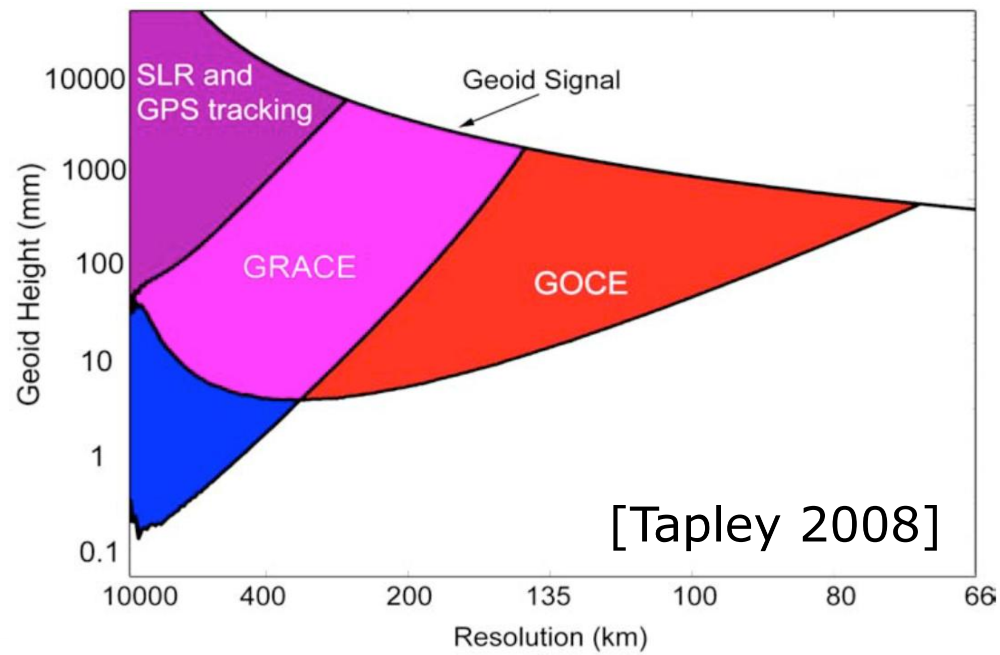
- Drag-free approach: 2 drag-free satellites w/ ranging + GPS
  - Accuracy: 10^{-10} m/s² - 10^{-15} m/s² (depends on satellite environment)
  - Drag force cancelled instead of measured → no dynamic range limit
  - TM-to-satellite coupling reduced
    - No suspension
    - cm gaps
  - Autonomous orbit maintenance
  - Precise drag and thrust measurements



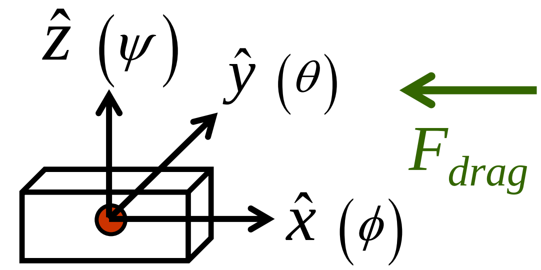
Benefits of Constellations

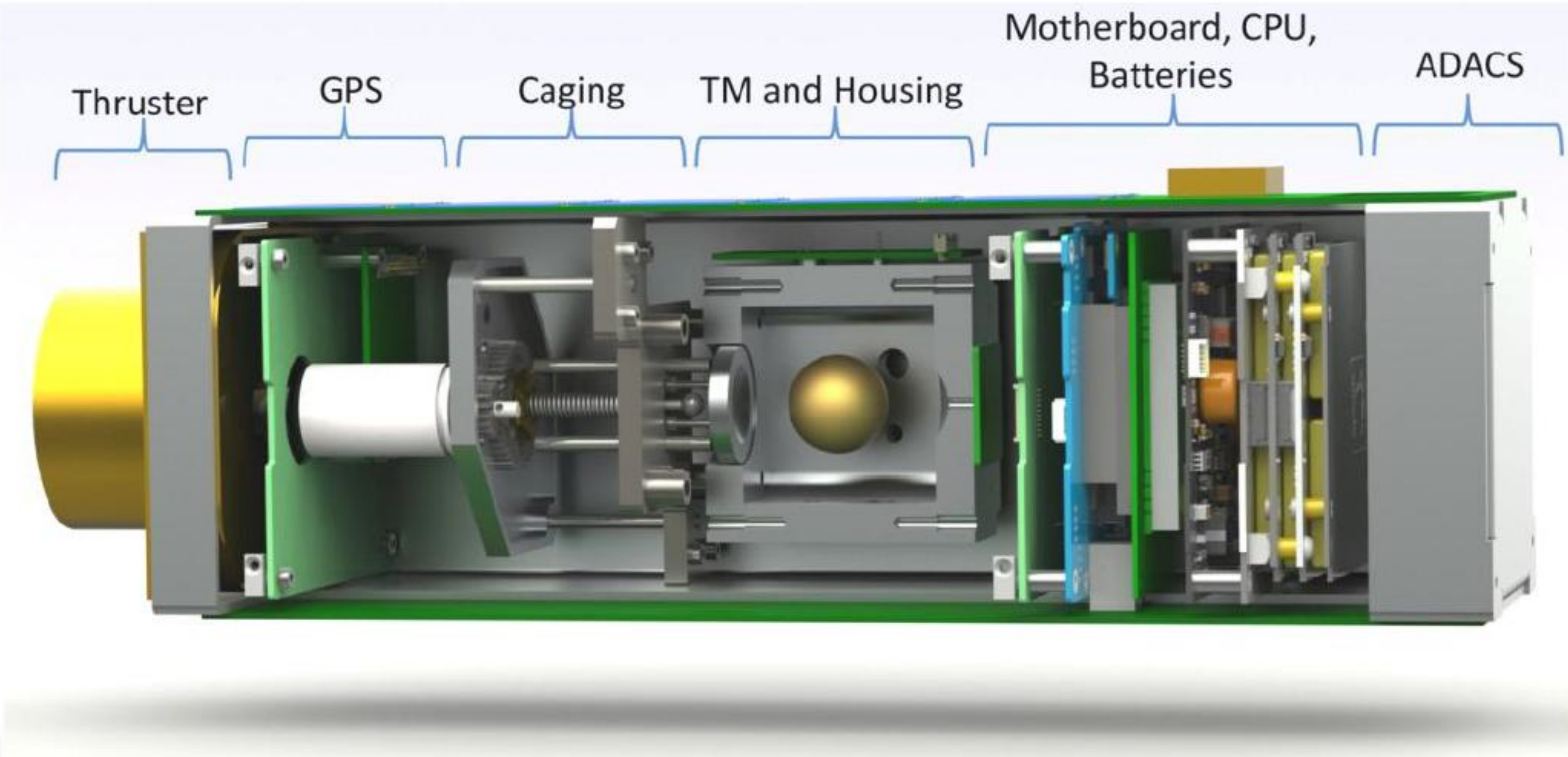
- Ranging + GPS data → Estimates of Earth's geopotential
  - Typically spherical harmonic coefficients
- Constellations:
  - Reduce aliasing (striping): polar orbit → mixed orbits
  - Increase temporal frequency: months → weeks



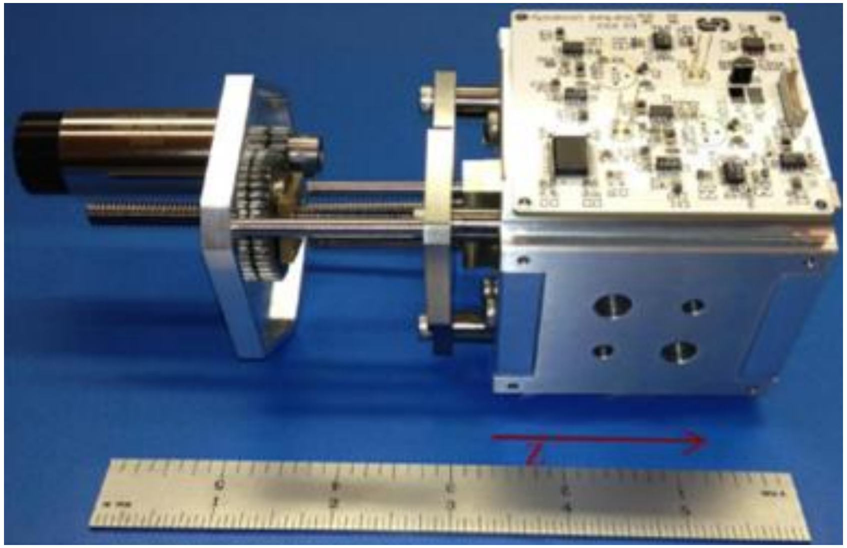


The Drag-free CubeSat

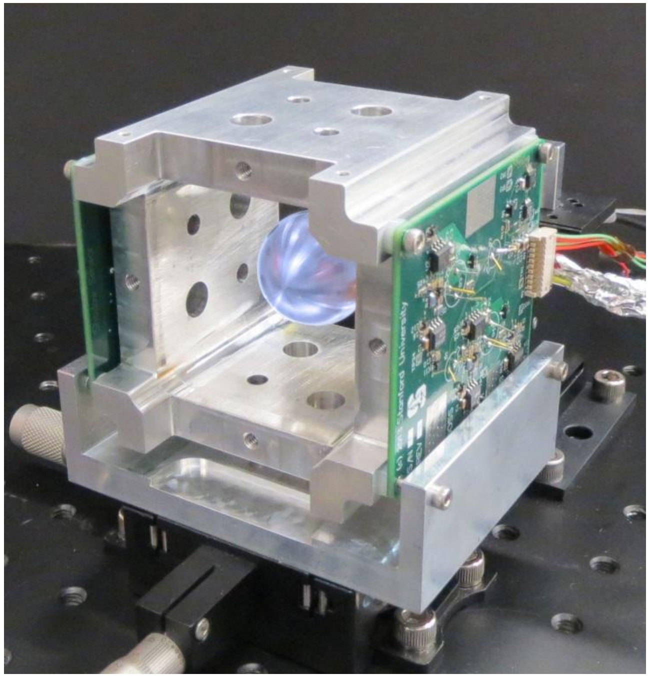




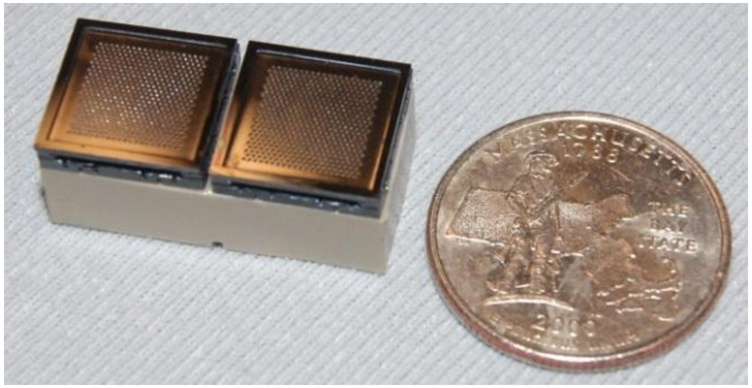
Hardware Development



Caging mechanism and housing



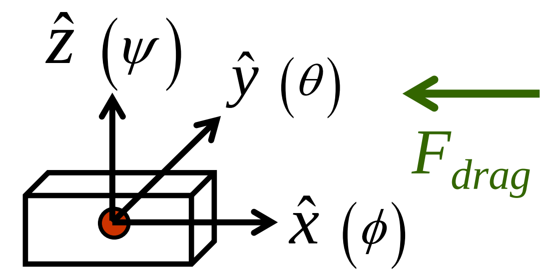
Differential optical shadow sensor



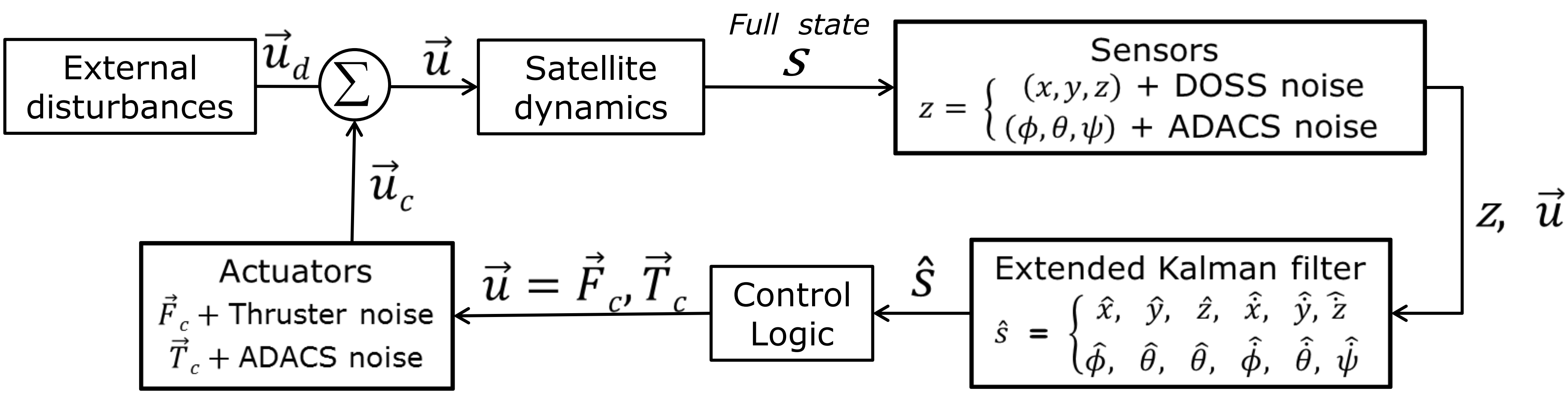
MIT ion Electrospray Propulsion System (iEPS)

Zero-G test flight

Drag-free and Attitude Control System

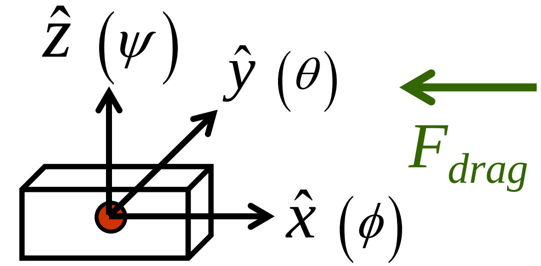


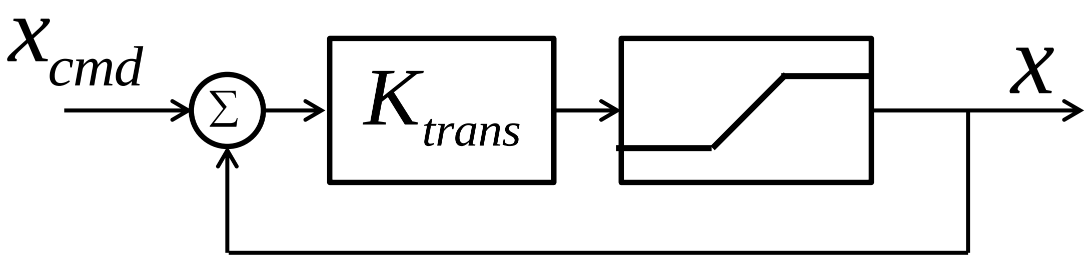
- Keep satellite CoM coincident with TM CoM
  - Requirement: ~ 10 μm/Hz$^{1/2}$
    → acceleration noise ~ 10^{-12} m/s^2 Hz$^{1/2}$
- Actuators:
  - Thruster: oppose drag force (max ~ 400 μN, minimum bit ~ 1 μN)
  - ADACS: point satellite "into the wind" (torque ~ 1 mN-m)
- Sensors:
  - DOSS: satellite position w.r.t. TM, ~ 10 nm/Hz$^{1/2}$
  - ADACS: attitude, ~ 0.1 deg (e.g. Blue Canyon, Berlin Space)



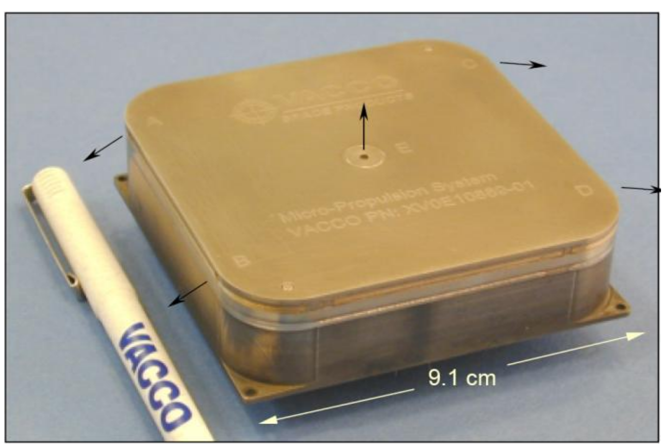
Along-track Translation Control

- Thruster compensates external drag force
  - x direction only



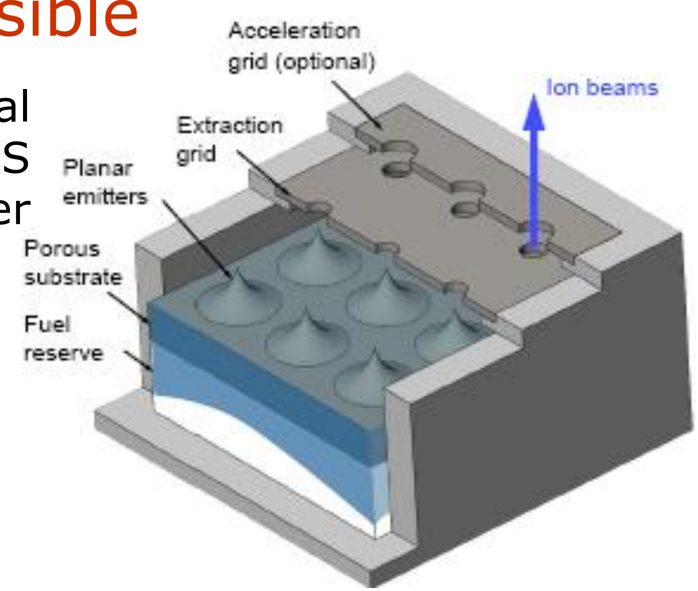


- On/off & proportional thrusting possible

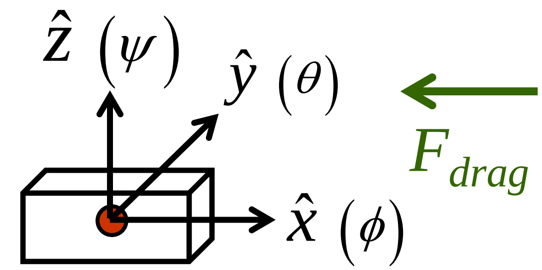


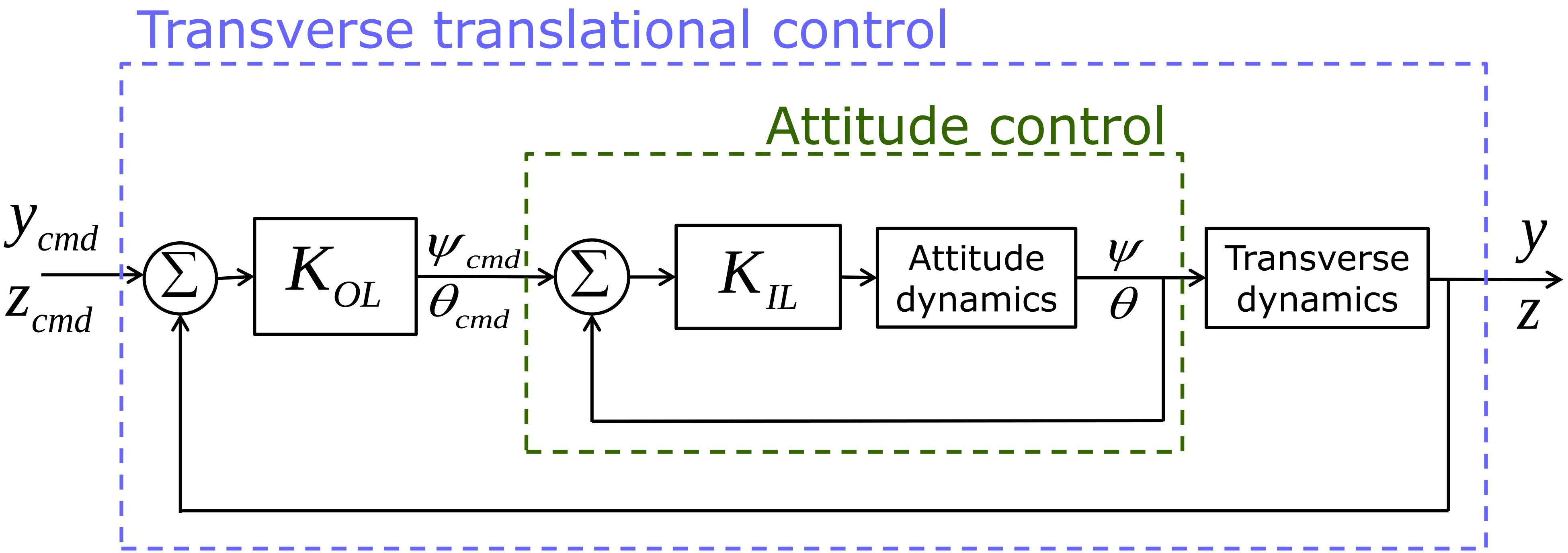
On/Off VACCO cold gas thruster

Proportional MIT iEPS thruster



Attitude Control

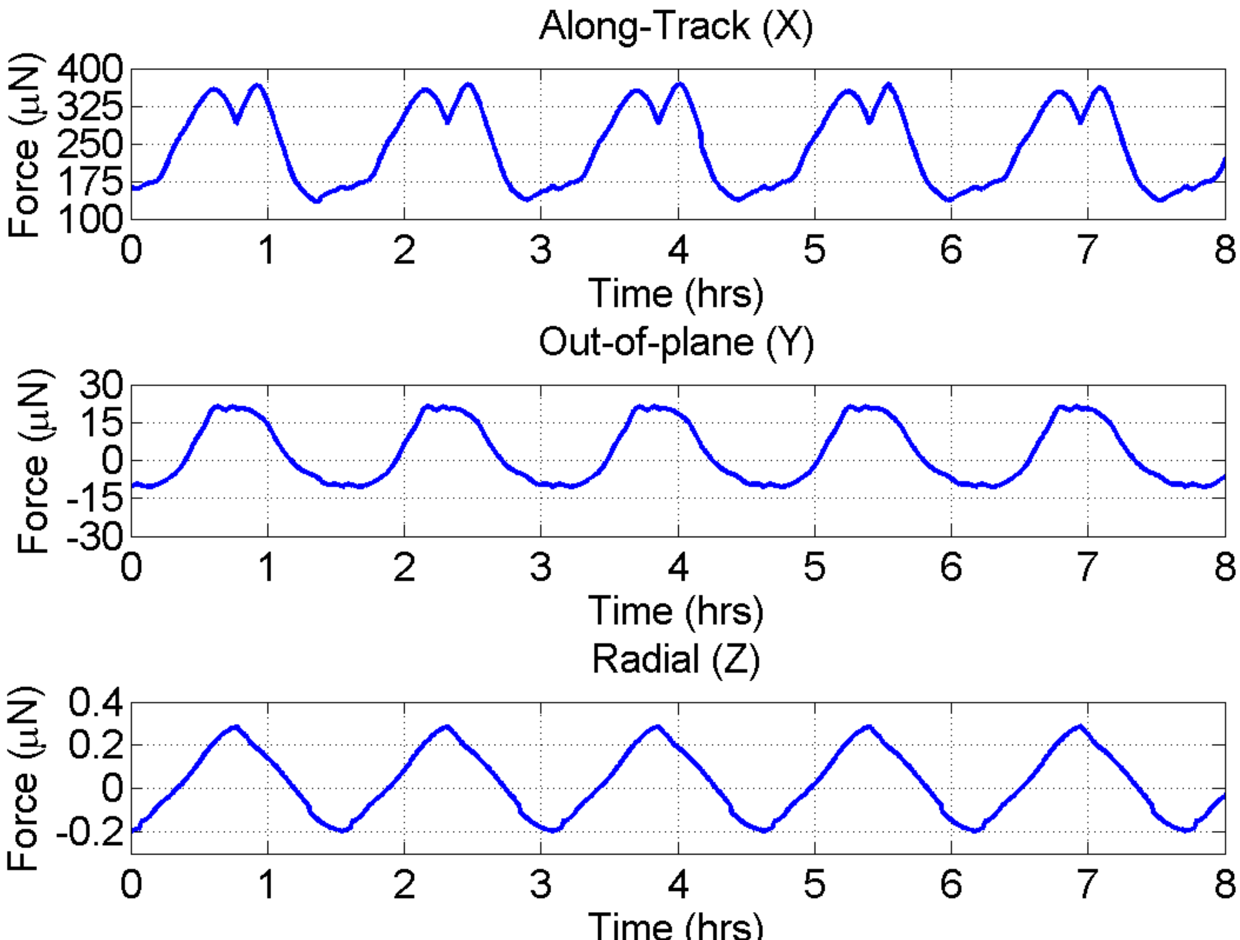




- Fast (~1 Hz) inner attitude control loop
- Slow (~0.1 Hz) outer transverse translation control loop

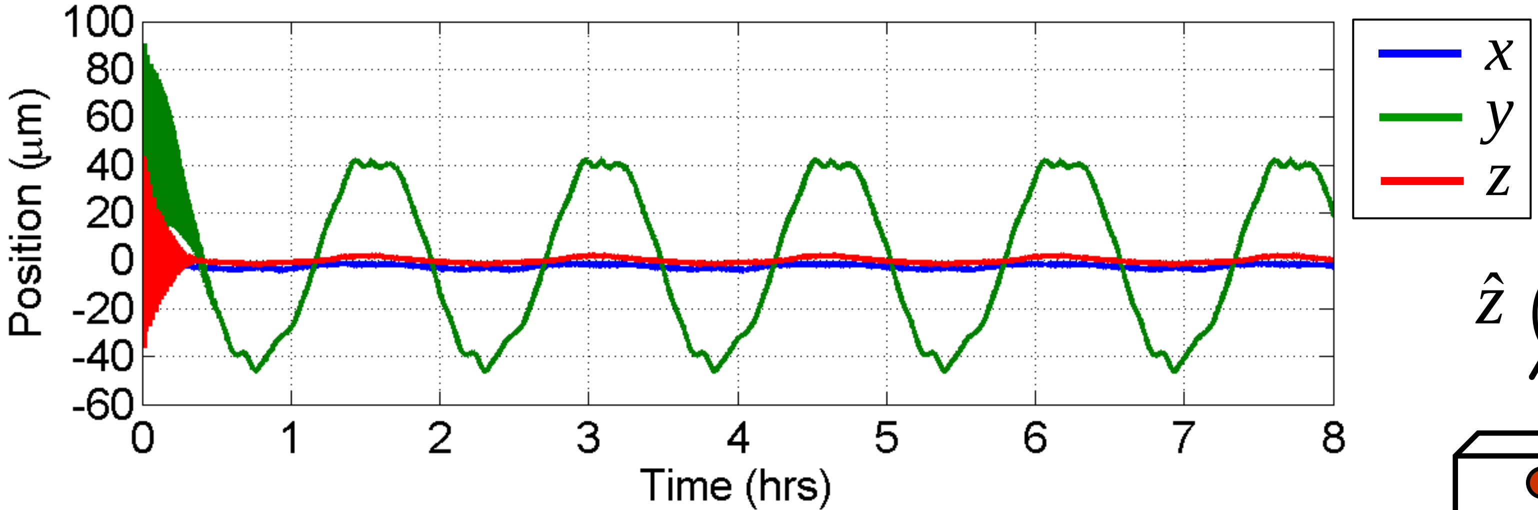
Drag Environment

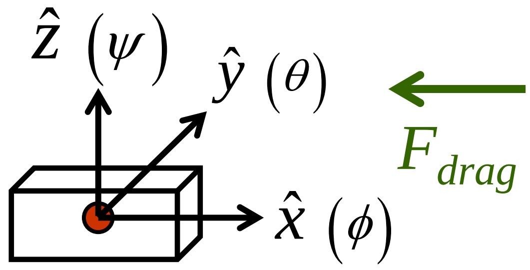
- 400 km circular polar orbit
- Atmospheric drag dominates (150-300 μN)
    - Horizontal Wind Model 07
    - MSIS density model
- Also modeled:
    - Solar rad. pressure
    - Earth albedo (TOMS)
- Out-of-plane ~ 5% of along-track

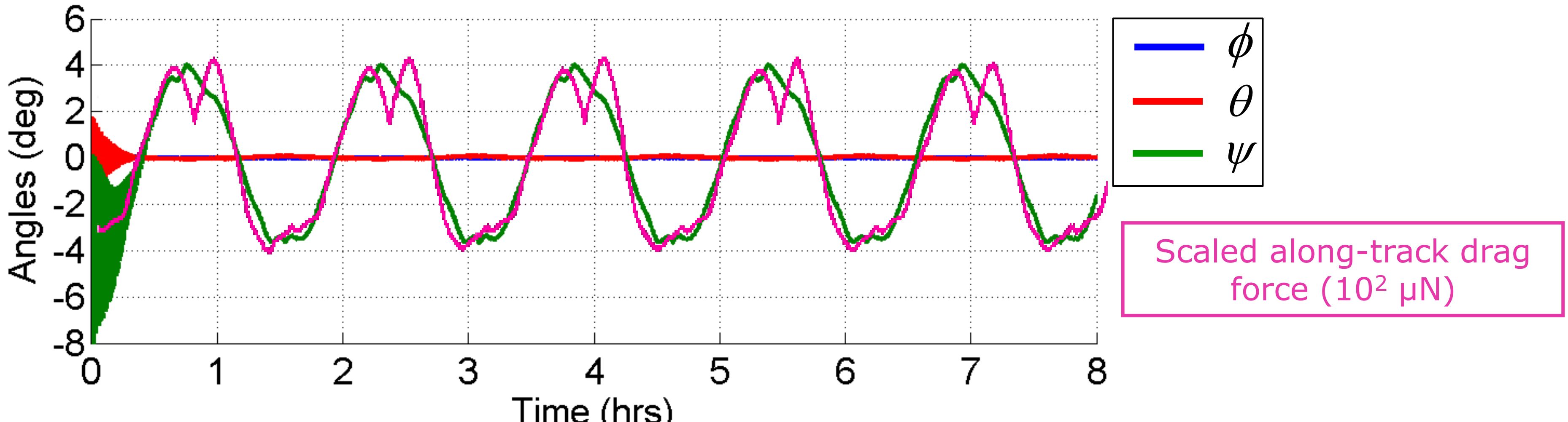


Simulated Results

- DFACS stable over many orbits
  - Position variations < 40 µm p-p, attitude tracks external force







Conclusions

- Constellations improve Earth geodesy beyond basic cost savings & increased spatial resolution → aliasing
- Precision drag-free small satellite platform feasible
- Launch schedule:
  - UV LED charge control satellite: March 2014 (Saudi Sat, Dnepr)
  - DOSS CubeSat: 2015-2016 (ELaNa)
  - Drag-free CubeSat: 2017 (???)
- Acknowledgments:

backup slides …

UV LED Small Sat

- Raise TRL of UV LEDs for charge control in space
- Flight unit build at NASA Ames
- Launch in March 2014
    - Saudi Sat on Russian Dnepr