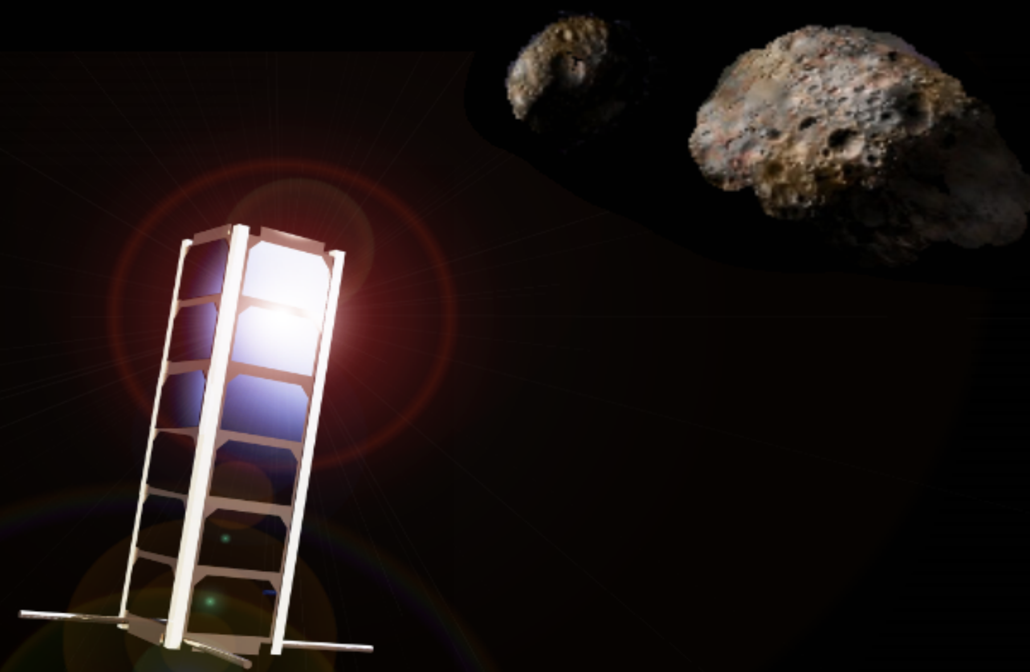
Low-Cost CubeSat Centrifuge Programs for Planetary and Space Science



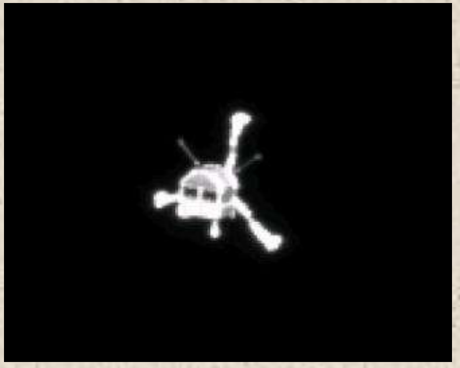
Erik Asphaug, Jekan Thanga, and the AOSAT Team

The Requirement

- **In situ exploration of comets and asteroids and the return of primitive samples can give insights into the origin of the solar system and the Earth, and the building blocks of life.**

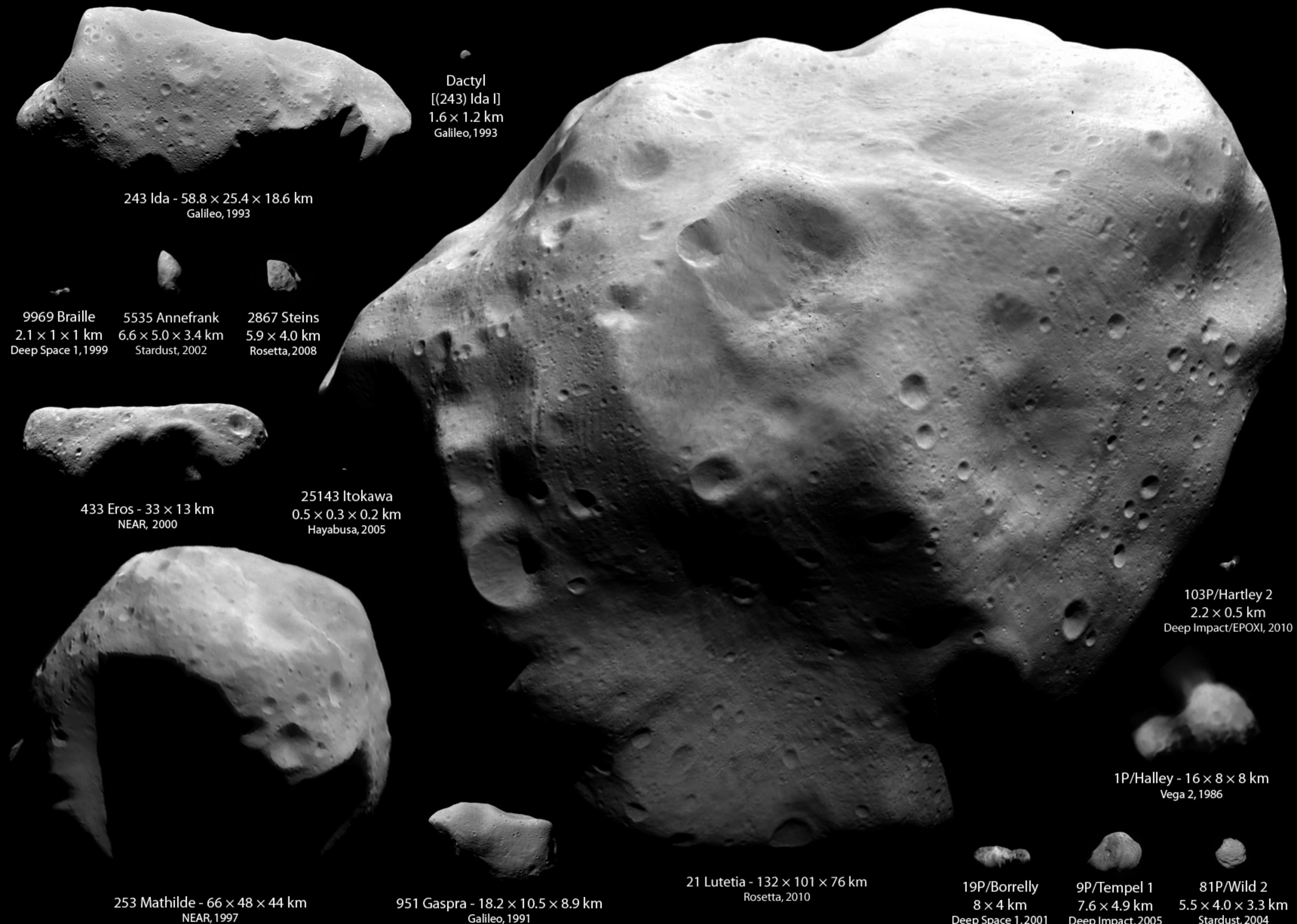
- **However, surface exploration of asteroids and comets remains a daunting challenge due to their milli-gravity and virtually unknown surface physics.**

- **This has resulted in complex designs and the loss of landers.**

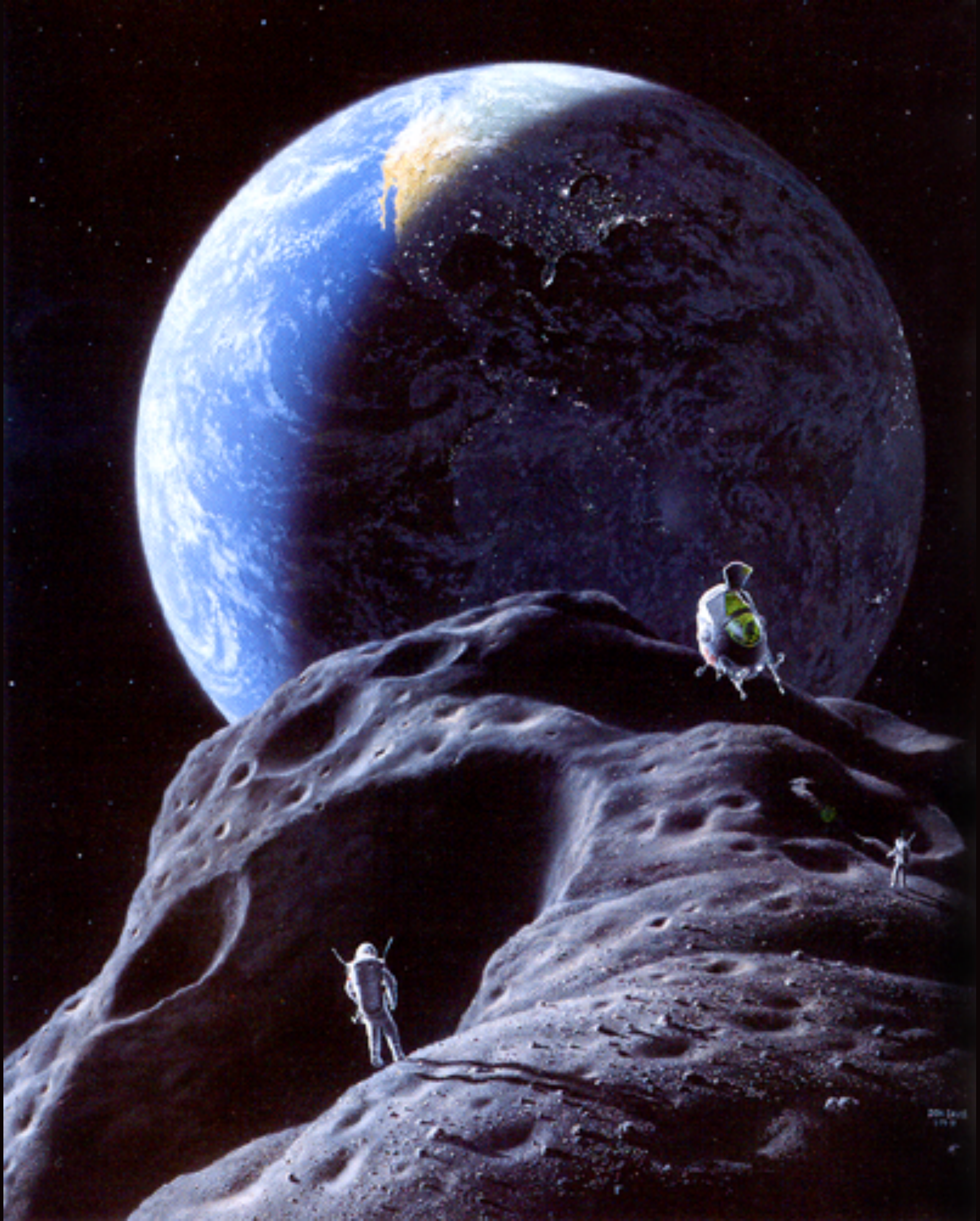


Philae/Rosetta (ESA)

NEO Exploration (NASA)

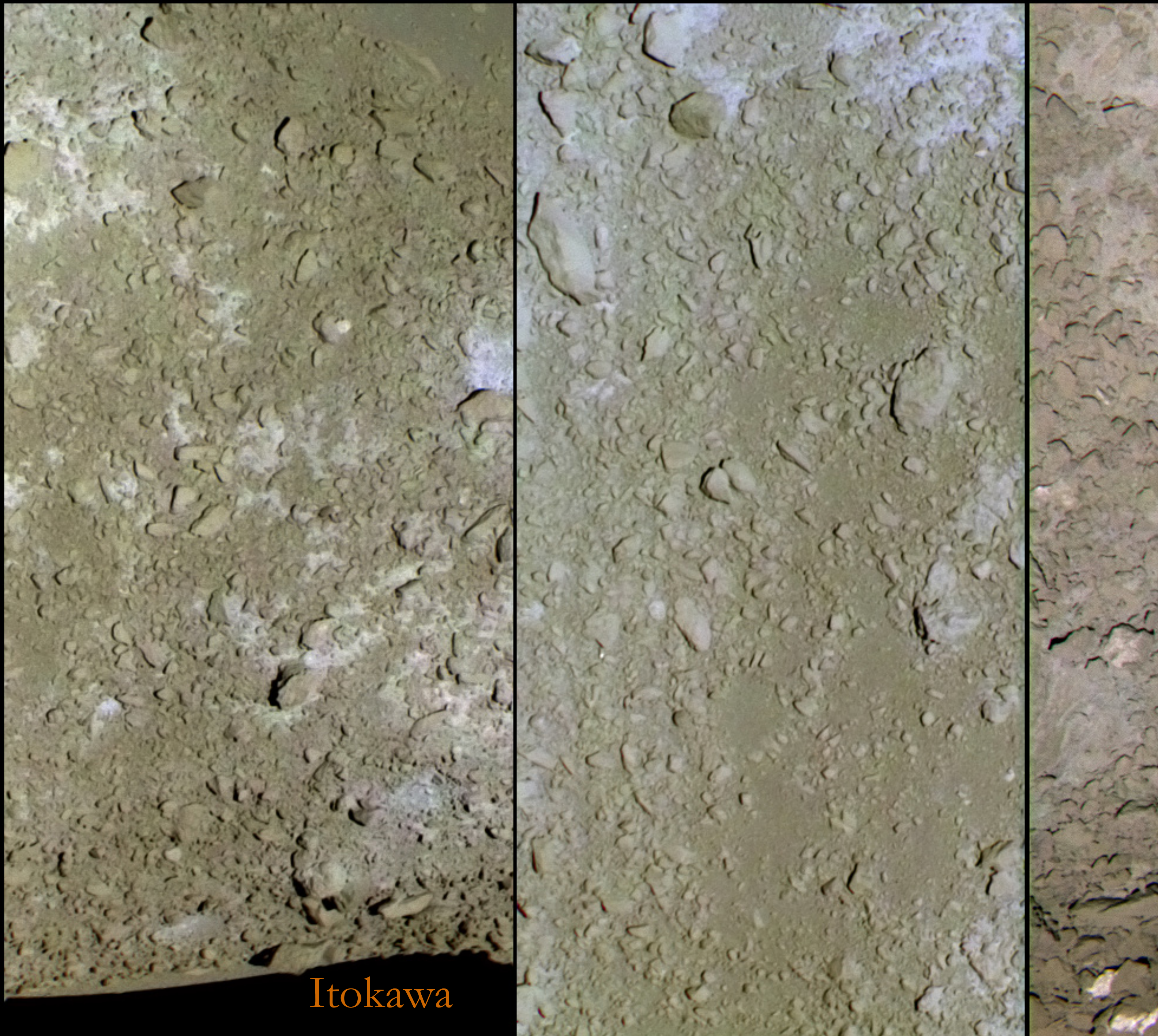


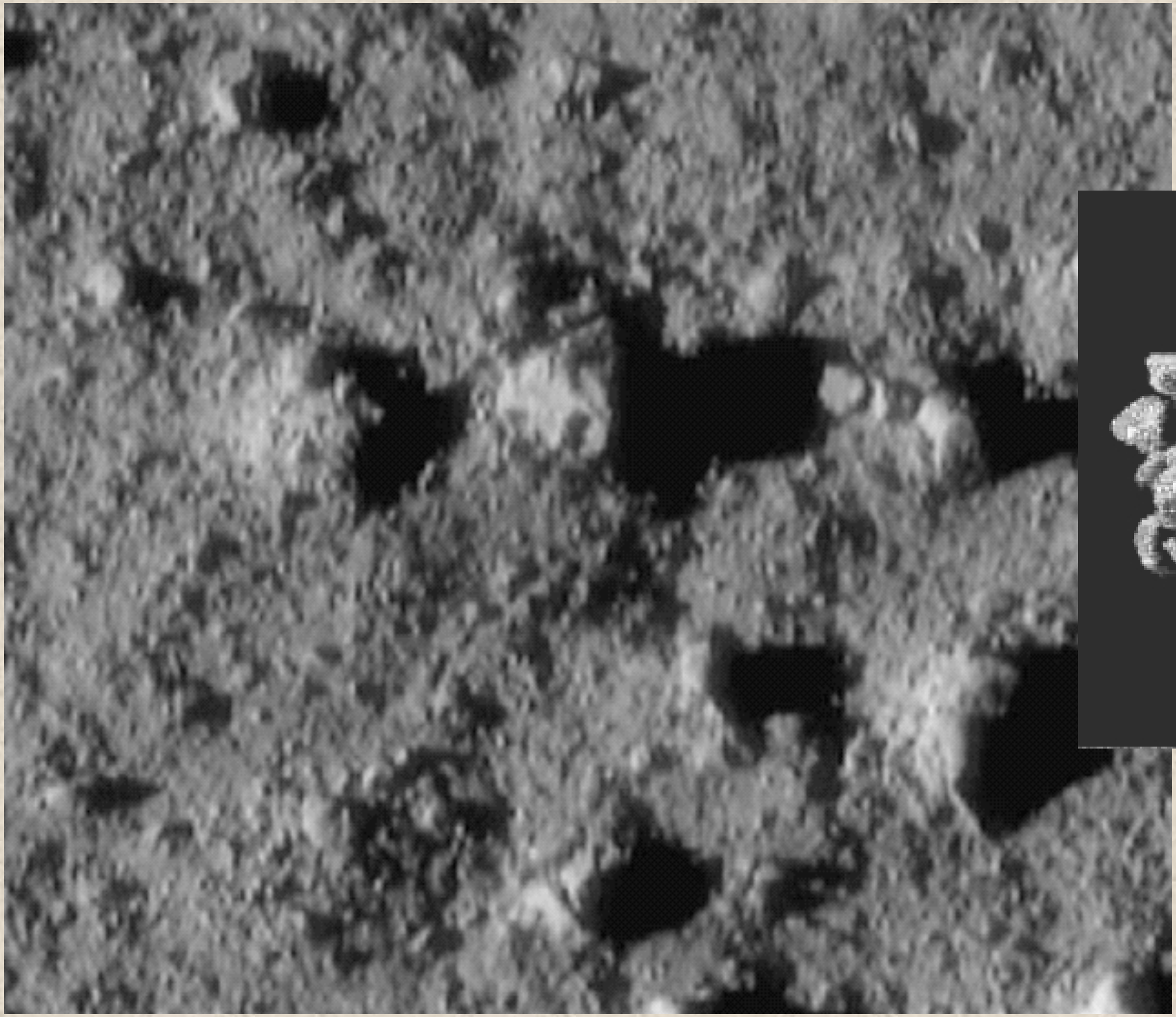
243 Ida - 58.8 × 25.4 × 18.6 km
Galileo, 1993
Dactyl
[(243) Ida I]
1.6 × 1.2 km
Galileo, 1993
9969 Braille
2.1 × 1 × 1 km
Deep Space 1, 1999
5535 Annefrank
6.6 × 5.0 × 3.4 km
Stardust, 2002
2867 Steins
5.9 × 4.0 km
Rosetta, 2008
433 Eros - 33 × 13 km
NEAR, 2000
25143 Itokawa
0.5 × 0.3 × 0.2 km
Hayabusa, 2005
103P/Hartley 2
2.2 × 0.5 km
Deep Impact/EPOXI, 2010
1P/Halley - 16 × 8 × 8 km
Vega 2, 1986
253 Mathilde - 66 × 48 × 44 km
NEAR, 1997
951 Gaspra - 18.2 × 10.5 × 8.9 km
Galileo, 1991
21 Lutetia - 132 × 101 × 76 km
Rosetta, 2010
19P/Borrelly
8 × 4 km
Deep Space 1, 2001
9P/Tempel 1
7.6 × 4.9 km
Deep Impact, 2005
81P/Wild 2
5.5 × 4.0 × 3.3 km
Stardust, 2004

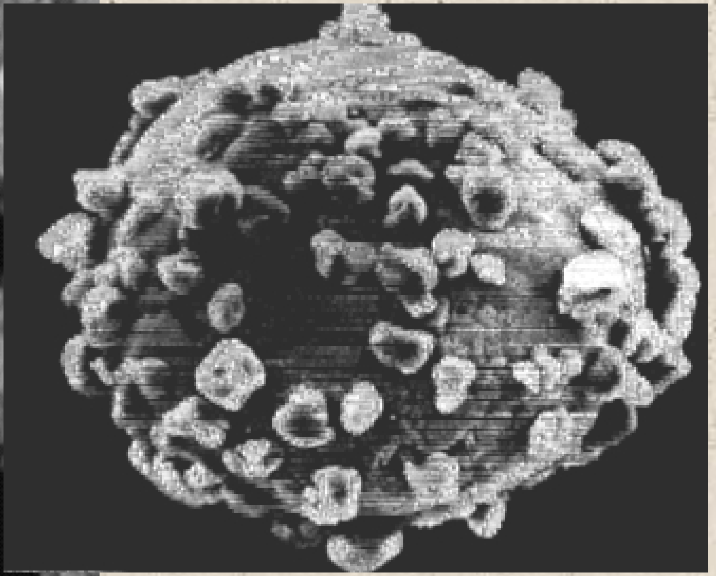


NEOs:

Not just
a passing
interest


Itokawa





Xerox toner (17um) stuck to a bead

NEAR mission, Eros descent image, Feb 2000
Largest boulders are ~2-3 m

NEAR final descent into asteroid Eros, Feb 2000

Science Motivation

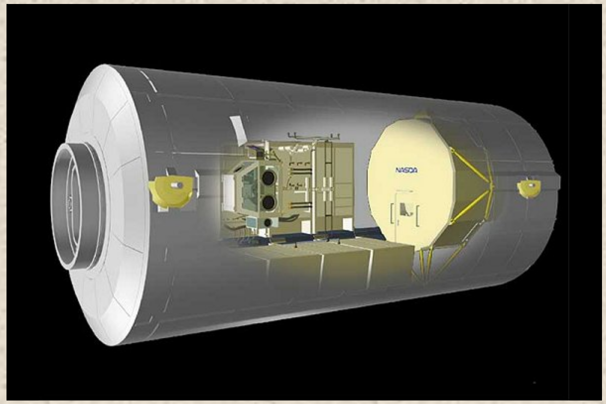
- We require access to stable long duration milligravity (<1 cm/s^2) conditions
  - to enable experiments to study asteroid/comet regolith physics and mechanical interactions
- Milligravity investigations are currently…
  - short duration (drop towers, parabolic flights)
  - noisy (vibration, stress unloading)
  - expensive and intolerant of mission risk (human-tended platforms e.g. ISS)
  - and not really milligravity at all! (noisy zero-gravity)

Science Motivation

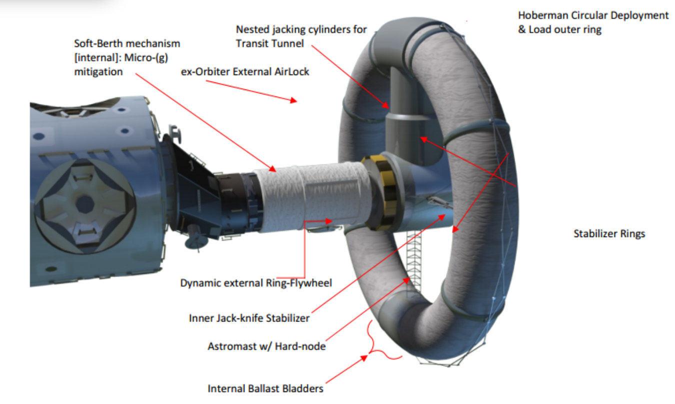
- CubeSats can provide a controlled environment for zero gravity experiments
  - low cost and risk; repeatable
  - past and forthcoming missions in zero-g
- <u>Centrifuge CubeSat</u> can obtain milligravity environment relevant to surfaces and interiors of asteroids, comets, small moons and planetesimals…
  - Basic science of small bodies
  - Test and validate technologies for mobility/anchoring/excavation

Technology Motivation

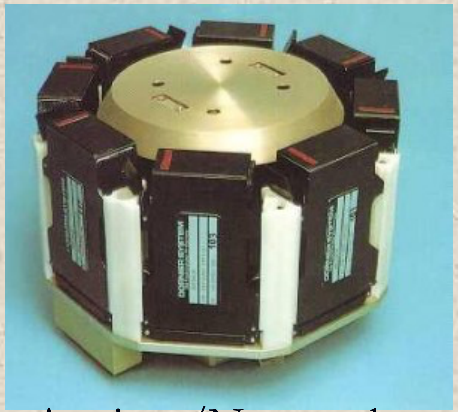
- Prevailing concept – connect rotating centrifuge to large stationary spacecraft
- A cause of spiraling cost and cancellations
  - Other solution – go large but expensive, high risk.
- Easier to have entire spacecraft rotate.



CAM Japanese Module on ISS (1990s)



NASA JSC's Nautilus X (2012)

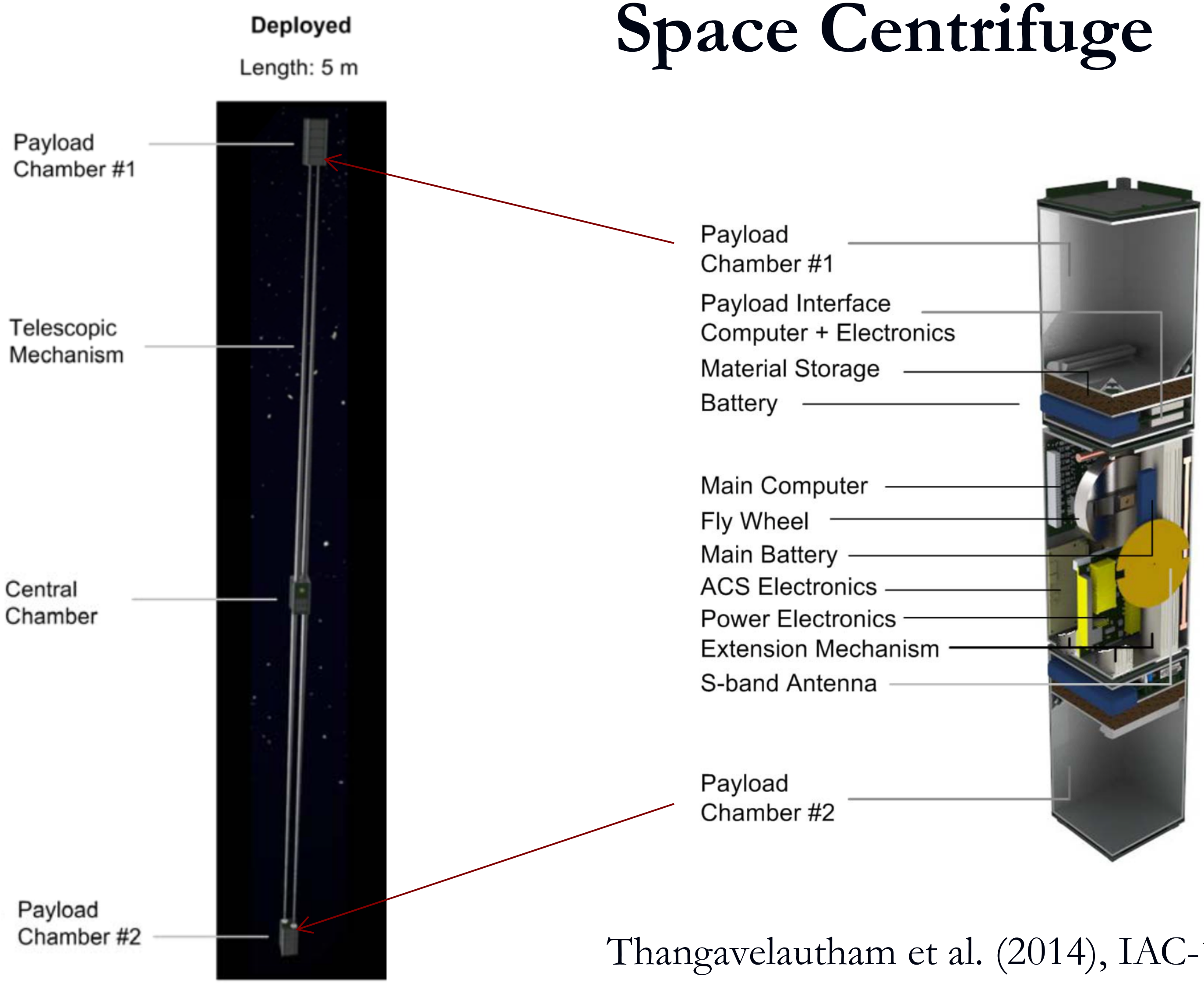


Astrium/Nanoracks Test-tube Centrifuge (2013)

Technology Motivation

- Gravity taken for granted in many vital processes
  - Manufacturing/materials
  - Chemical processes
  - Living systems
  - Food production
- <u>Concept of rotating spacecraft to produce artificial gravity never shown before.</u>
  - Requirement for low gravity for asteroid simulation also minimizes risk of spacecraft tumbling

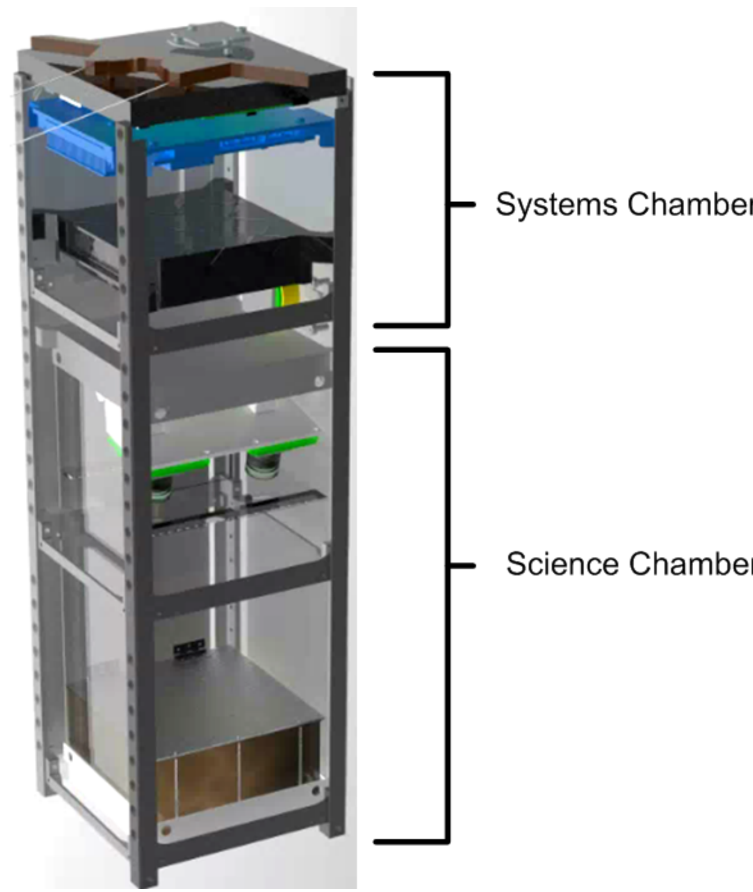
Space Centrifuge



Thangavelautham et al. (2014), IAC-14-A2.5.6

AOSAT-1

- Asteroid Origins Satellite (AOSAT) will simulate asteroid surface conditions using a cubesat centrifuge laboratory in Earth orbit.
- AOSAT designed capability provides a cleaner low-gravity environment than exists onboard the International Space Station, and with no risk to humans.



Asphaug & Thangavelautham (LPSC 2013)

AOSAT 1 System Overview

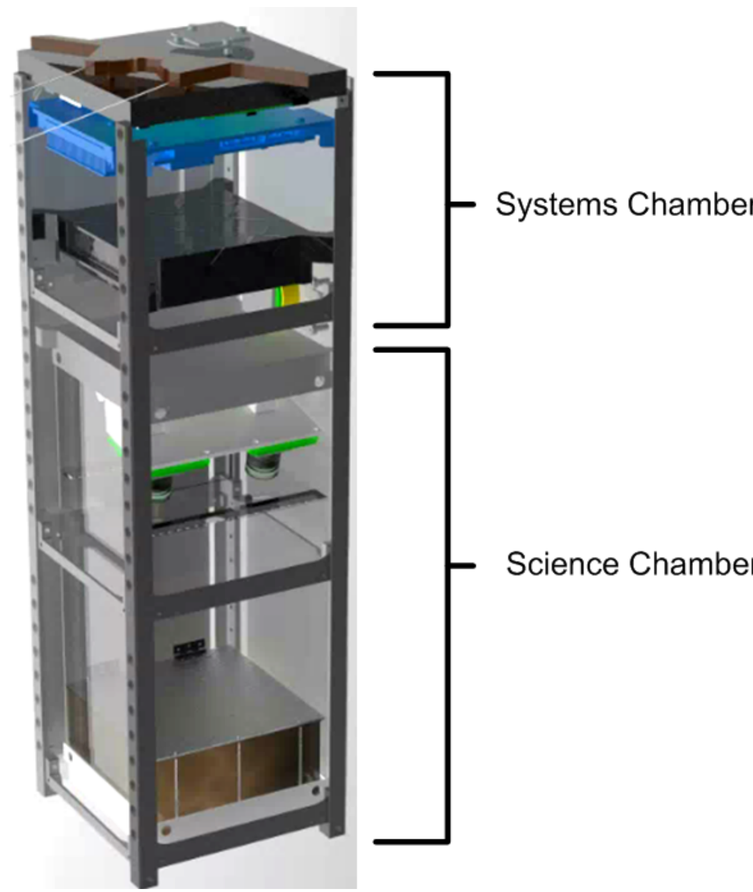
Mass: 3.9 kg spacecraft
Volume: 3U
Power: 4 W (avg.), 10-12 W peak
Orbit: LEO or Sun Synchronous

<u>Science Payload AOSAT 1</u>

- Cameras (4) on ‘top’ / possible servo
- LED strips (2 sets) on top and sides
- Regolith (300 g, deployed in chamber)
- Piezo-vibrators (2) on ‘bottom’

<u>Concept Payloads (open to ideas!)</u>

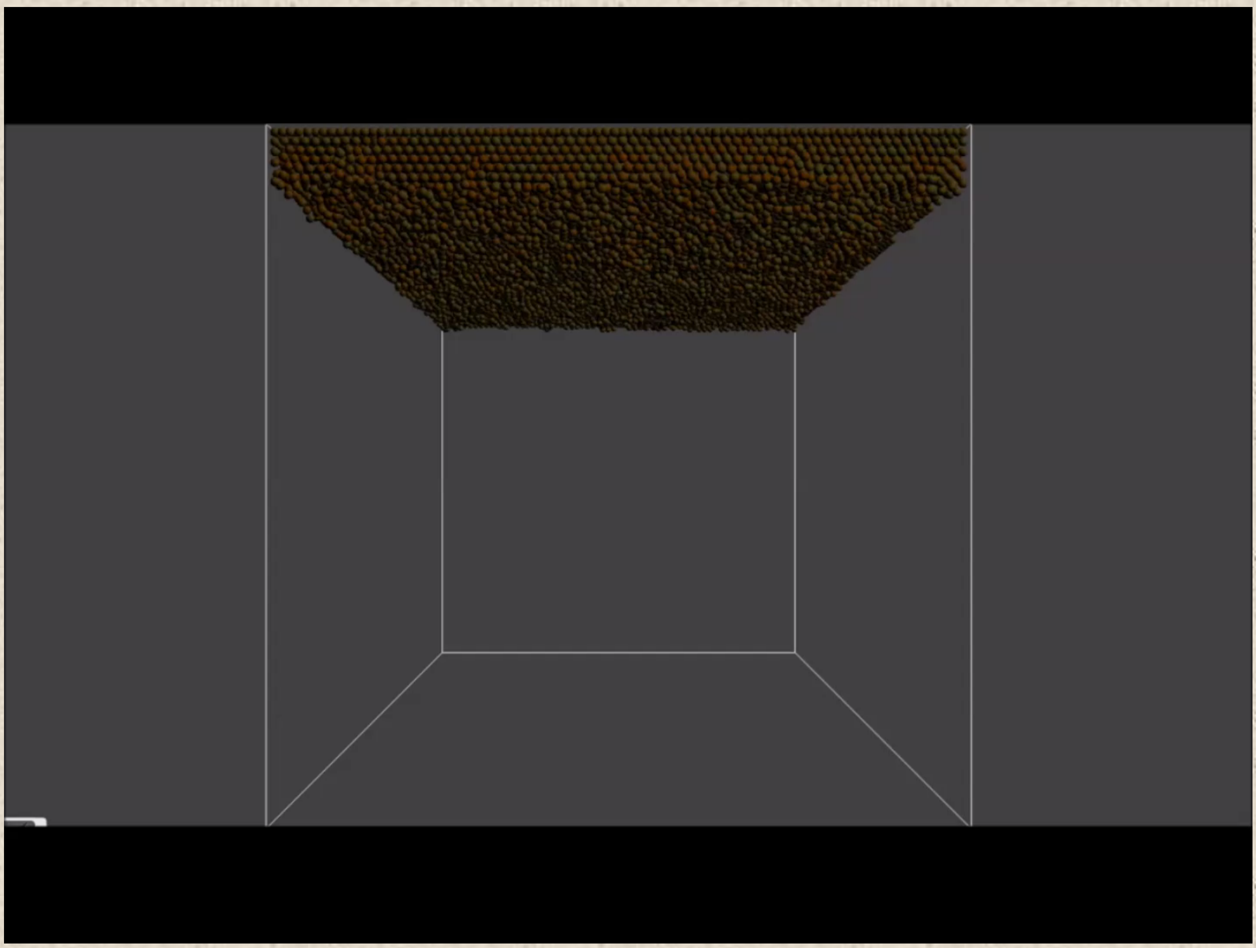
- Pea-shooter, gas jet
- Mechanisms/manipulators/mobility
- Liquids, biology studies



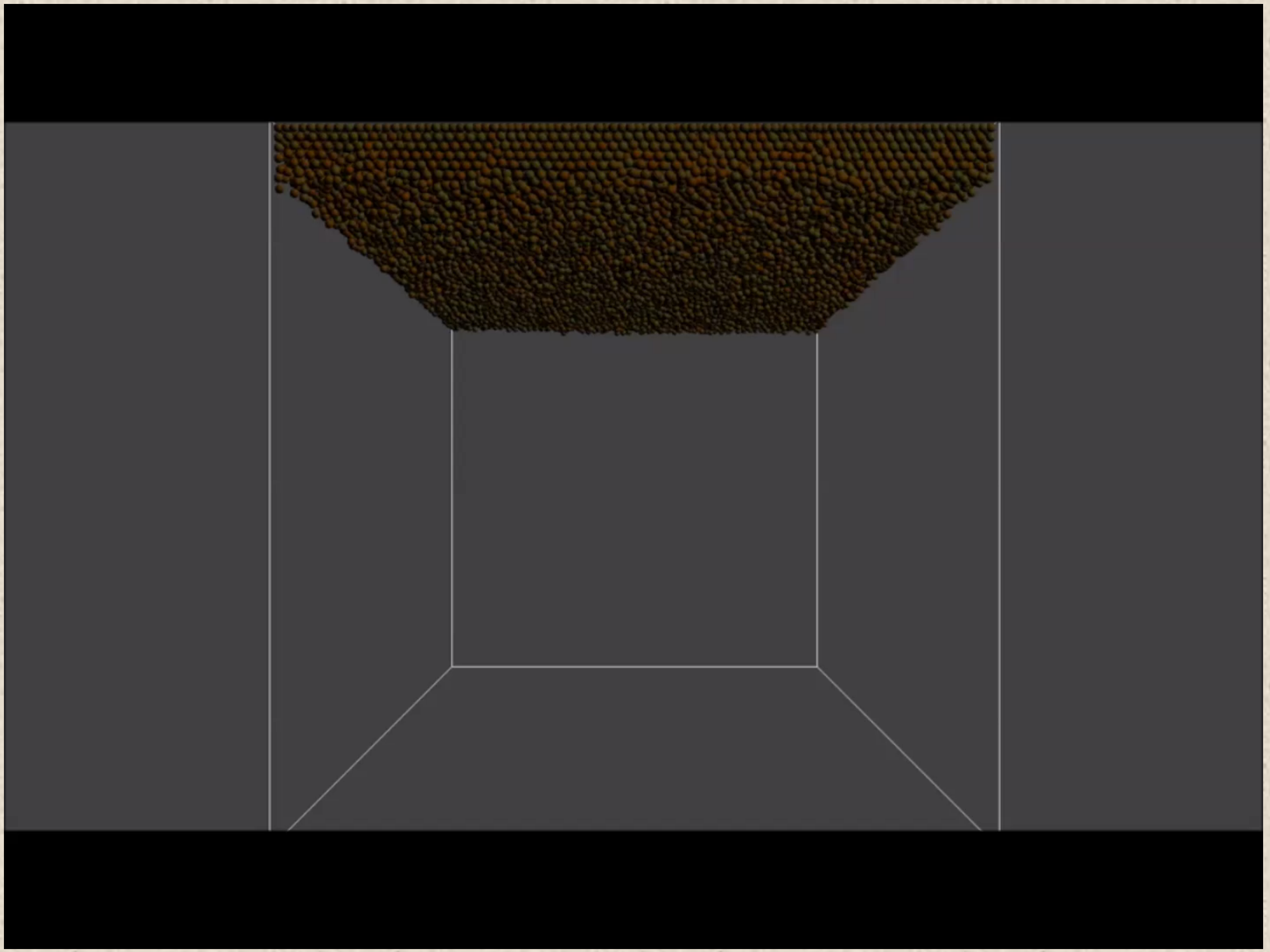
Science Traceability Matrix – AOSAT 1

Science Question	Science Objective	Measurement Requirement	Mission Requirement
How did solar system formation begin?	Conduct long term experiments to study particle coagulation	-Images, movies of particle coalescence	-Experiment chamber -Regolith deployment -Camera imaging system and illumination -Data downlink
What is the mechanical behavior of small body regolith?	Conduct sandbox experiments into equilibrated low-gravity beds of regolith	-Images, movies of regolith movement and stability -Vibrational behavior of regolith	-Stable spin of the above system to 1 rpm -Vibration sources -Bead-deployer

Simulation – Centrifuge Experiments (0.01g)

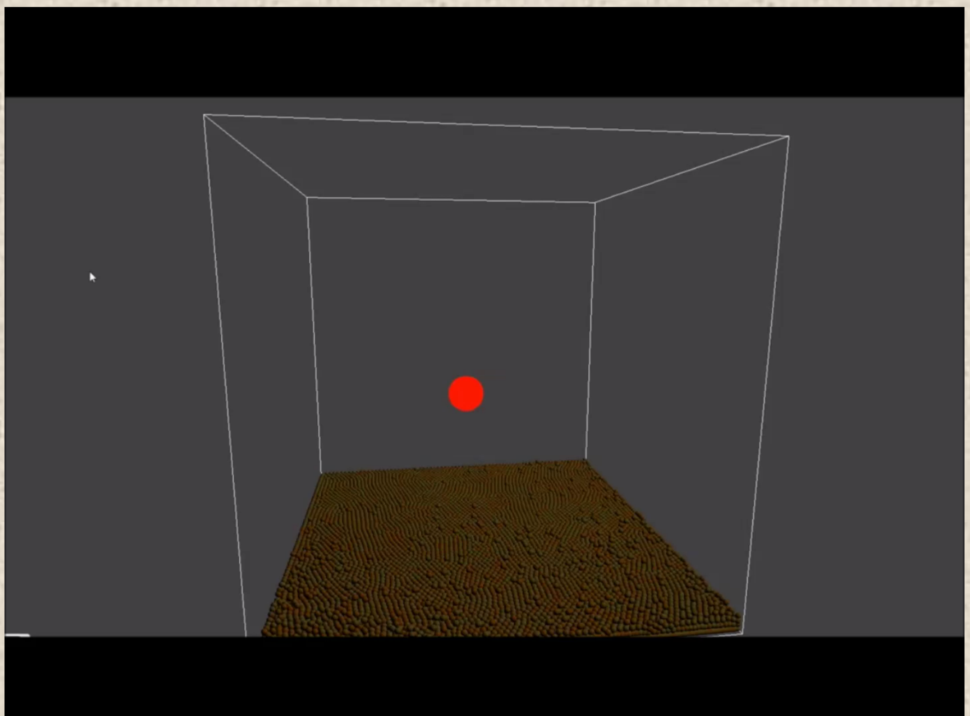


Simulation – Centrifuge Experiments (0.0001g)

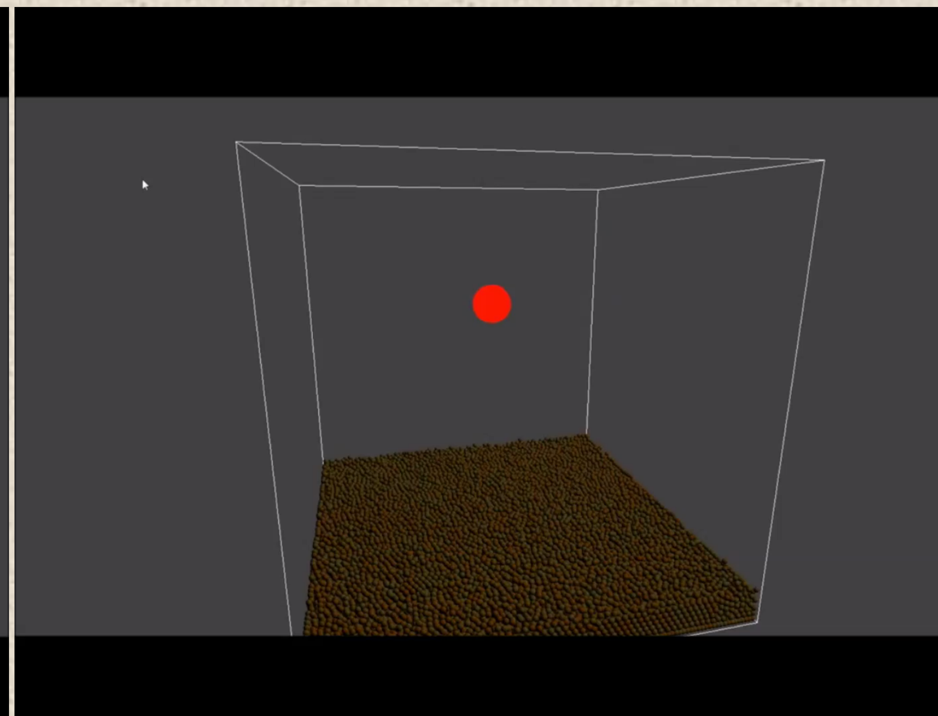


Simulation – Bead Interaction

0.01 g

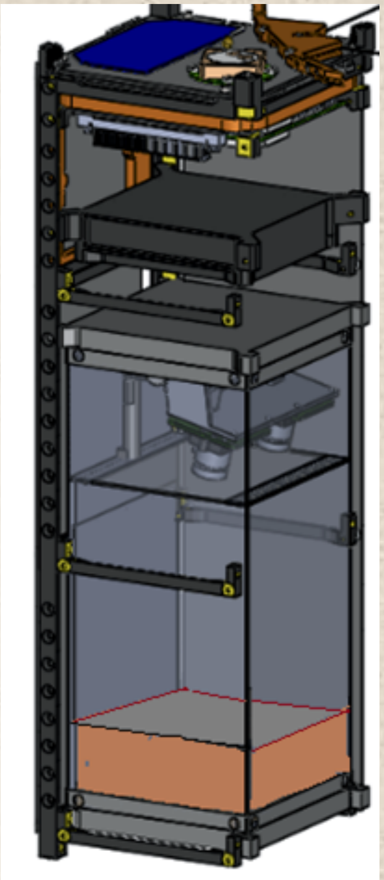


0.001 g



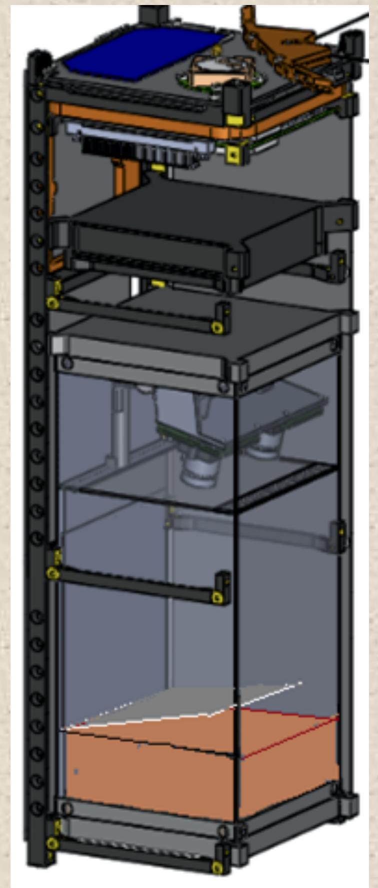
Concept of Operations: Primary Mission

Detumble



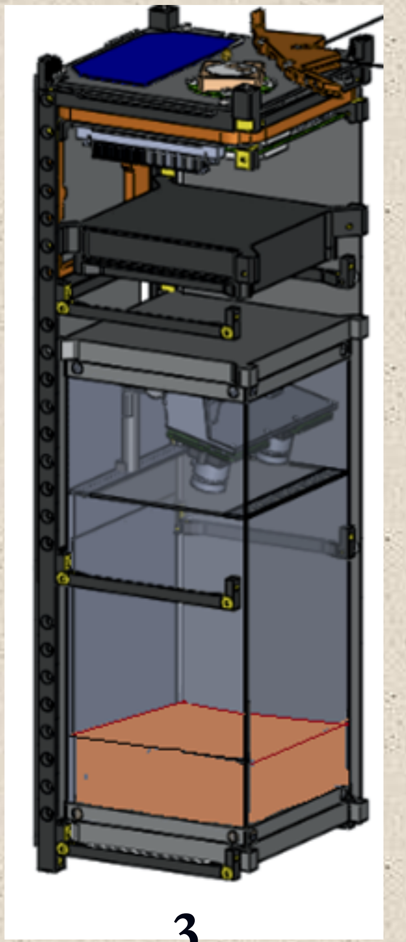
1

Release Regolith



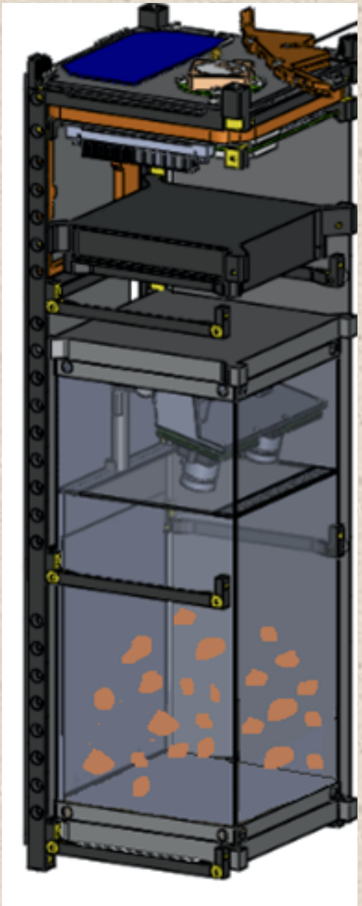
2

Free Float Regolith



3

Vibrate Regolith



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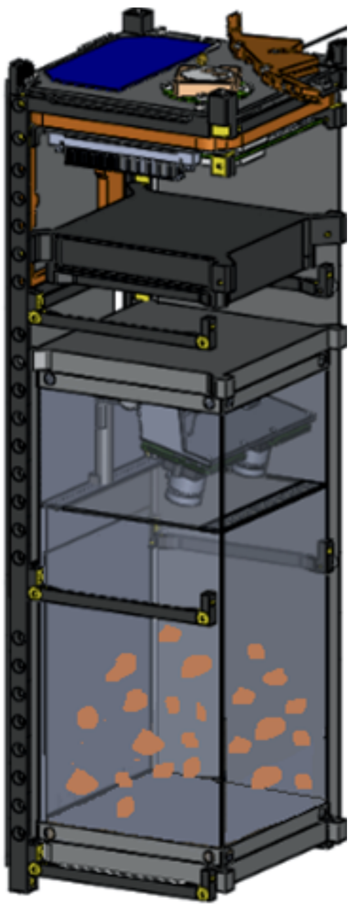
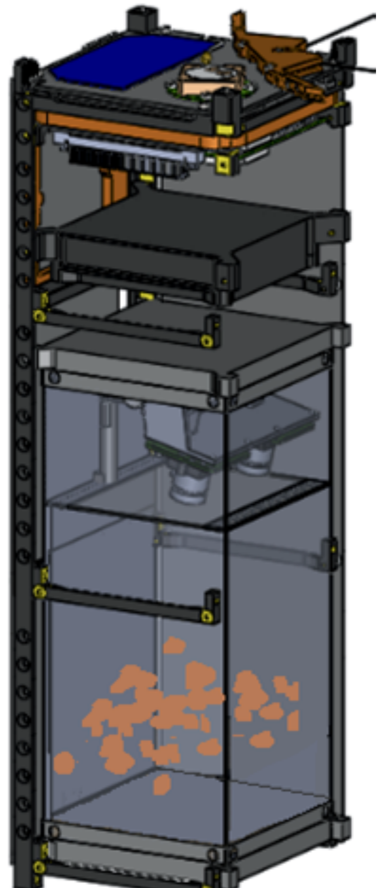
Concept of Operations: Primary Mission

Observe Regolith



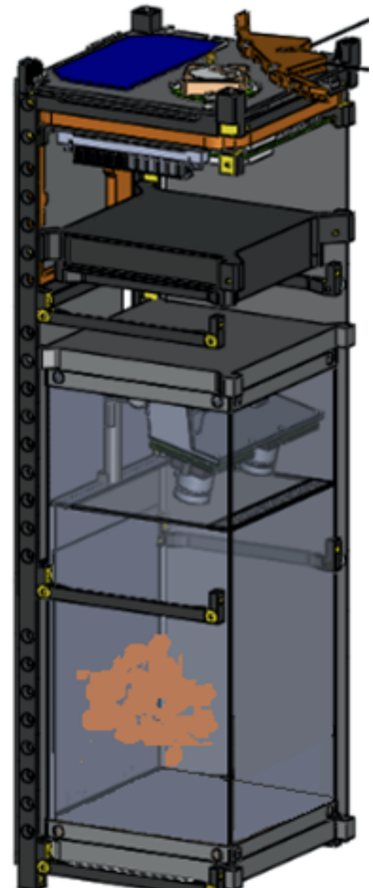
5

Aggregation ?



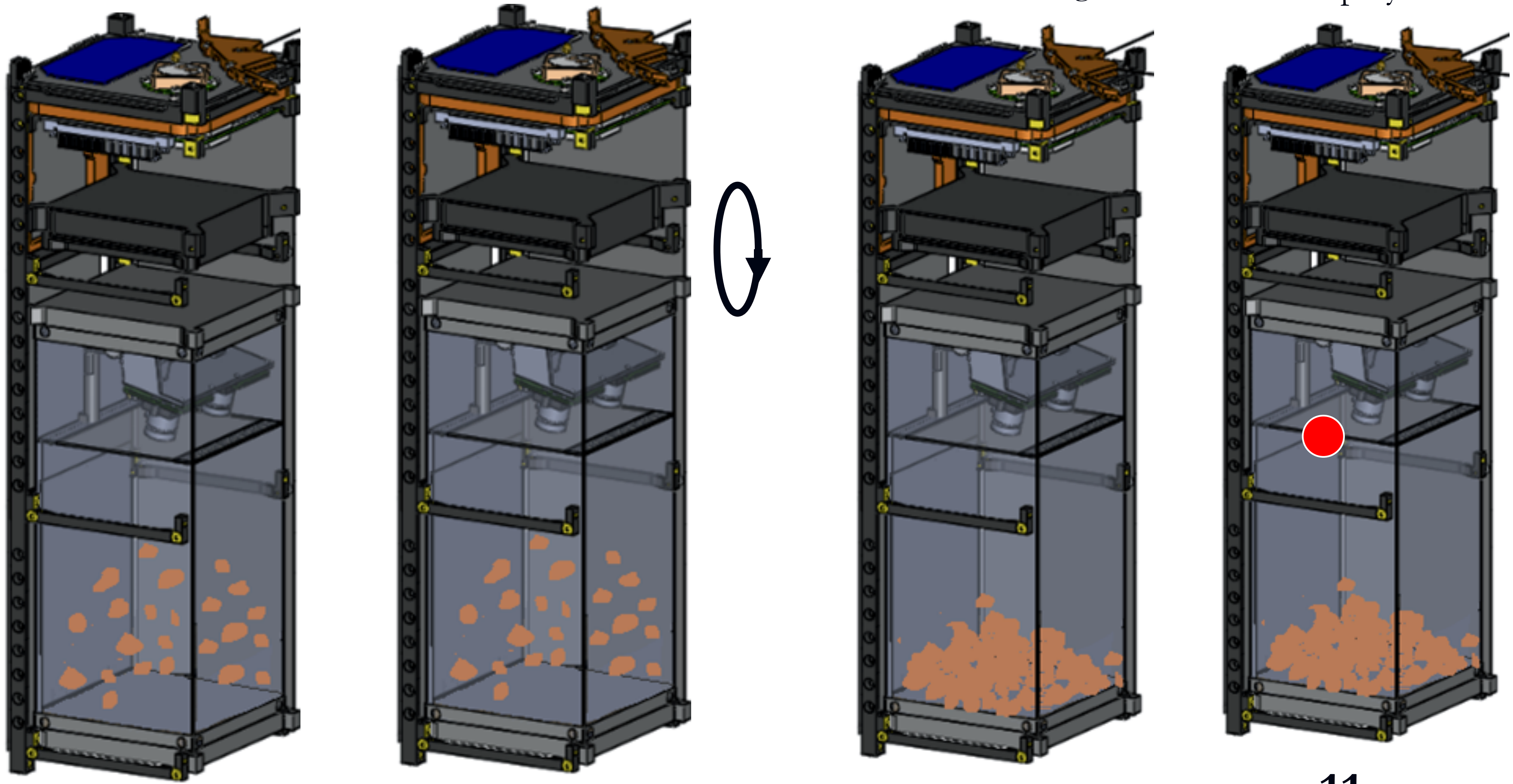
6

Aggregation ?



7

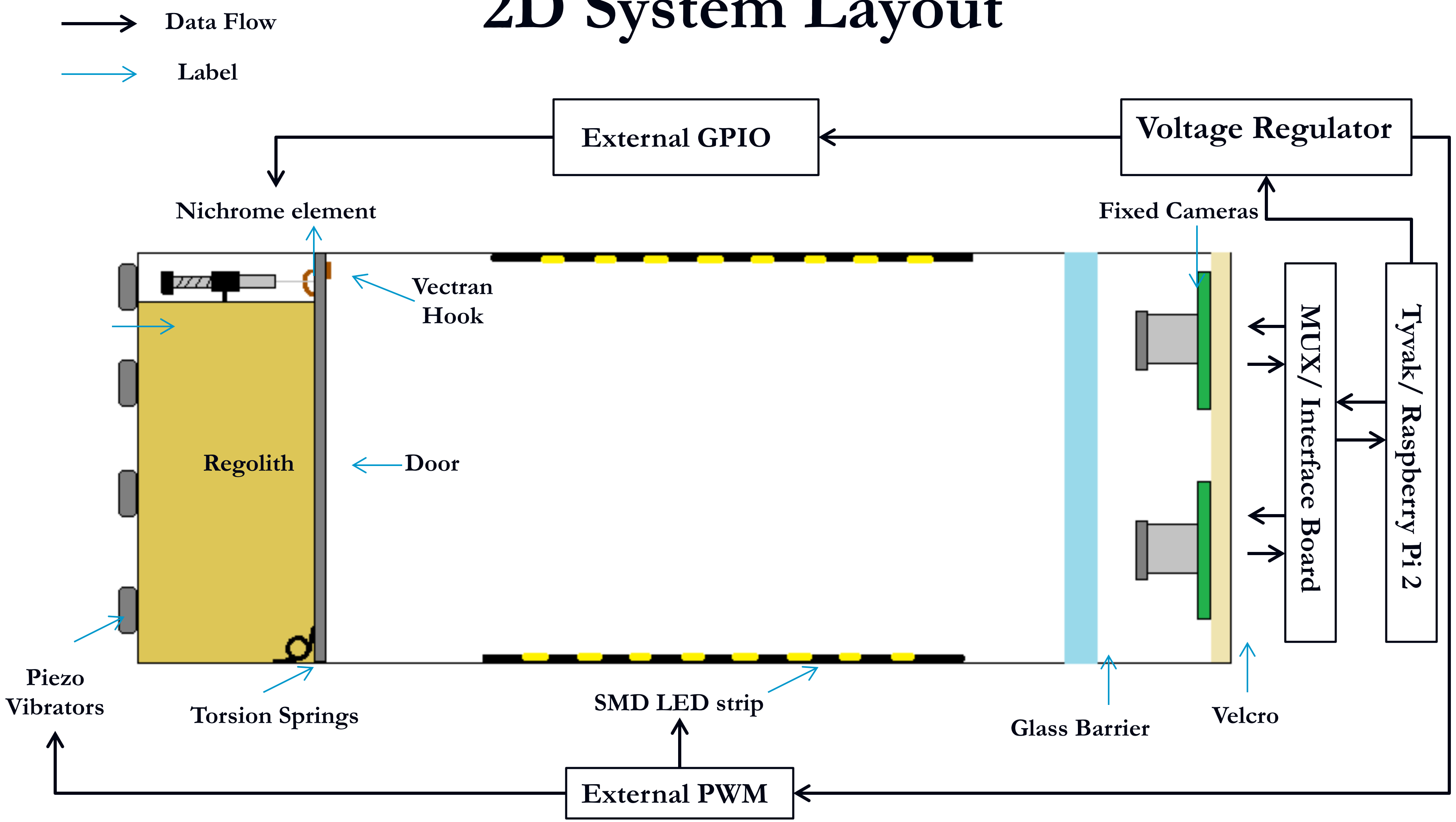
Concept of Operations: Tertiary Mission



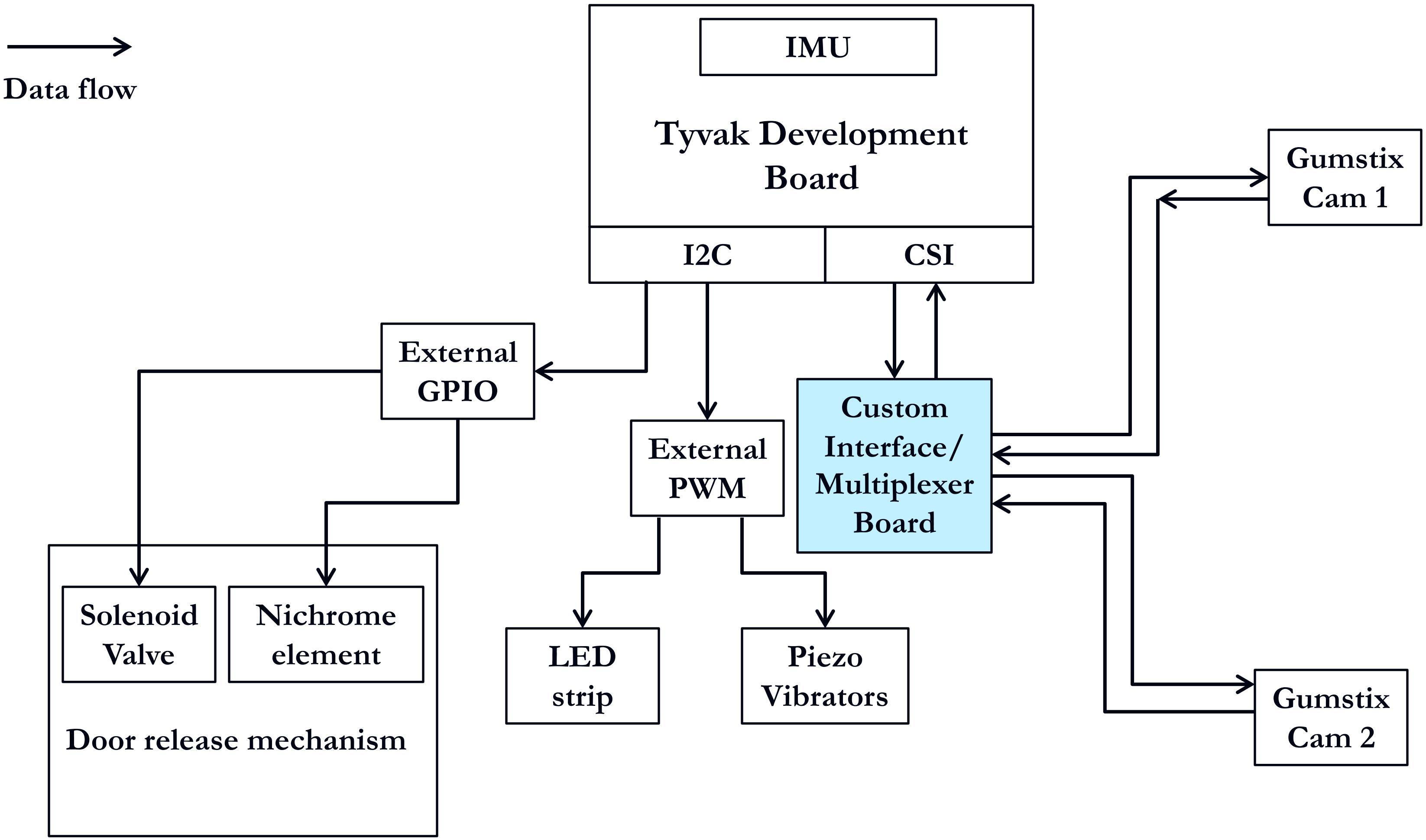
Engineering Model – Science Payload

System	Component	Selection
Imaging	Camera	Gumstix CASPA VL
	Multiplexing and Interfacing board	Needs to be custom designed and built
Door release	Thermal wire cutter	Custom design modified for manufacturability
	Solenoid actuator	Sparkfun 5V solenoid
	Interfacing board	MCP23017 - i2c 16 input/output port expander
Regolith agitation and illumination	Regolith agitation	Piezo-electric vibrating elements
	Illumination	SMD LED 3528 with LC2 Connector
	Interfacing board	Adafruit 16-Channel 12-bit PWM/Servo Driver - I2C interface - PCA9685

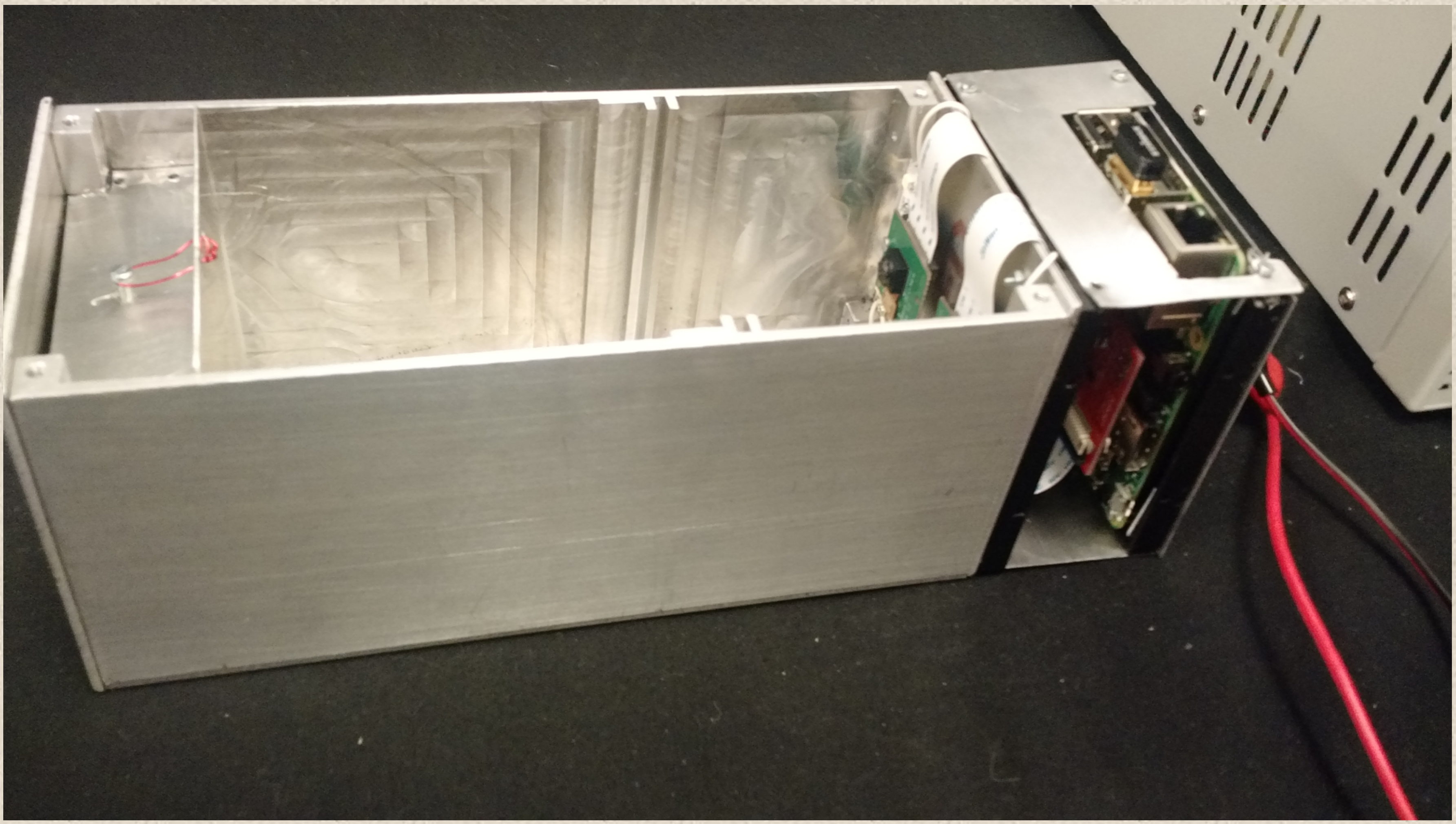
2D System Layout



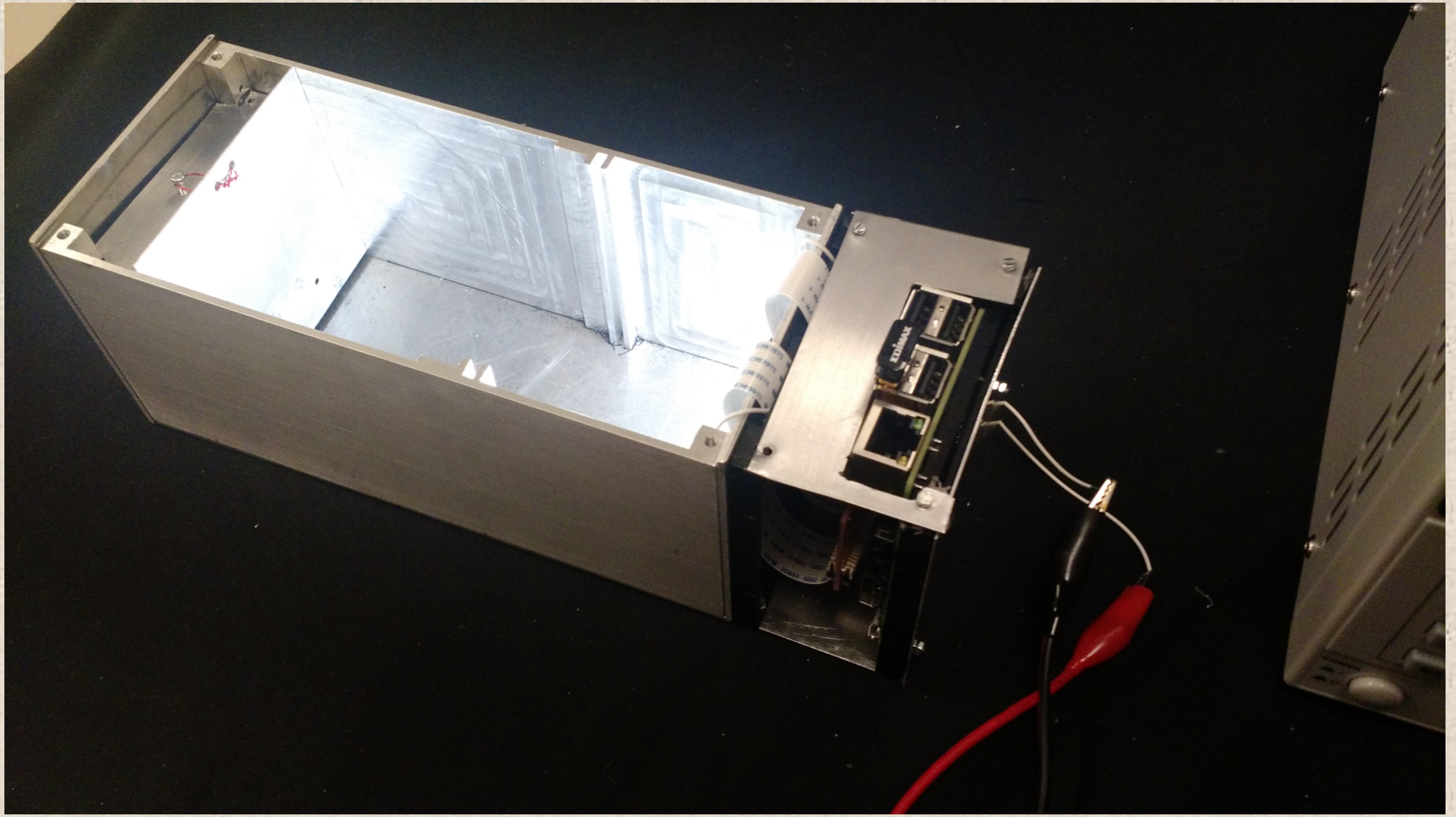
System Architecture



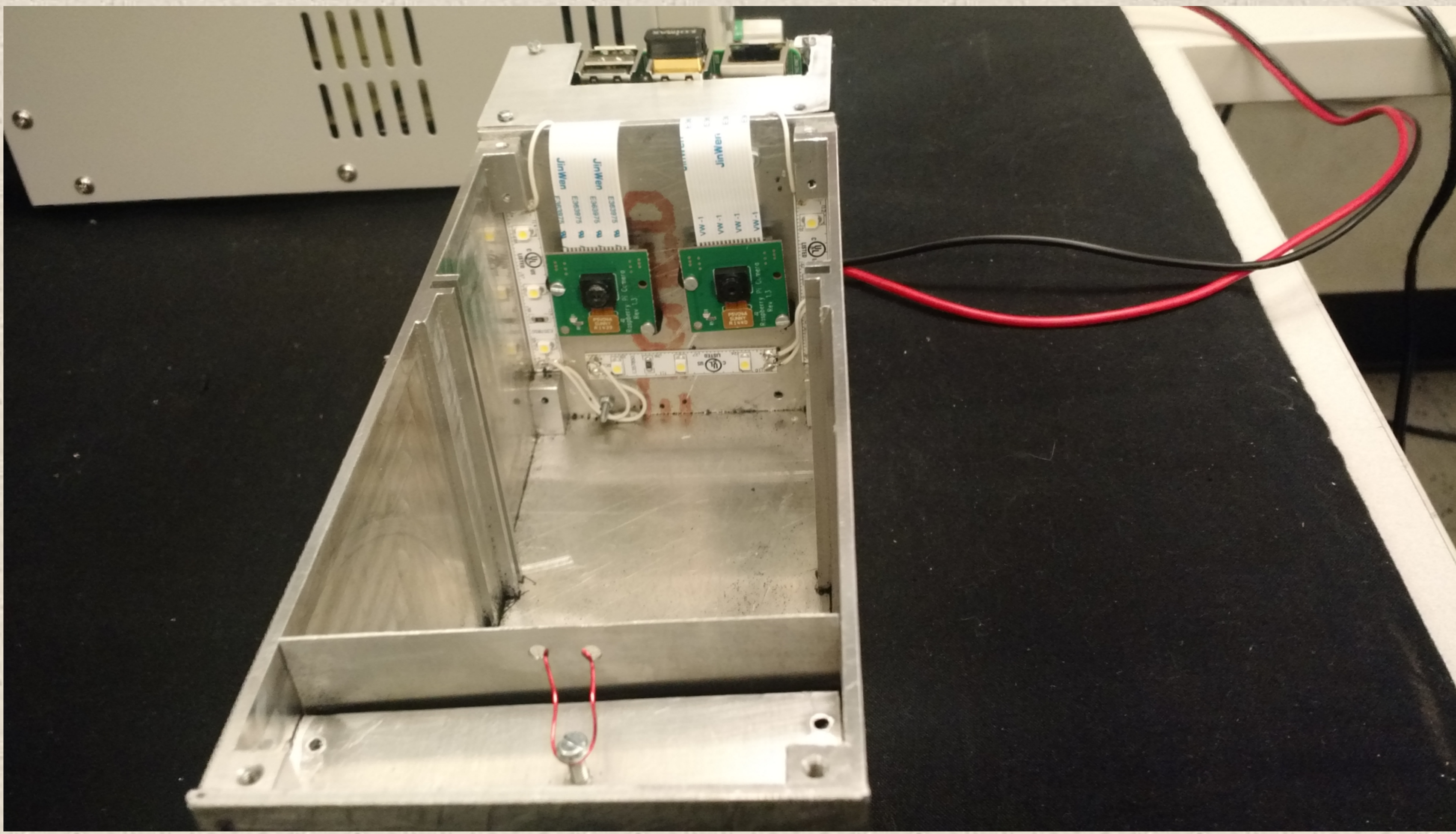
Engineering Model – Science Payload



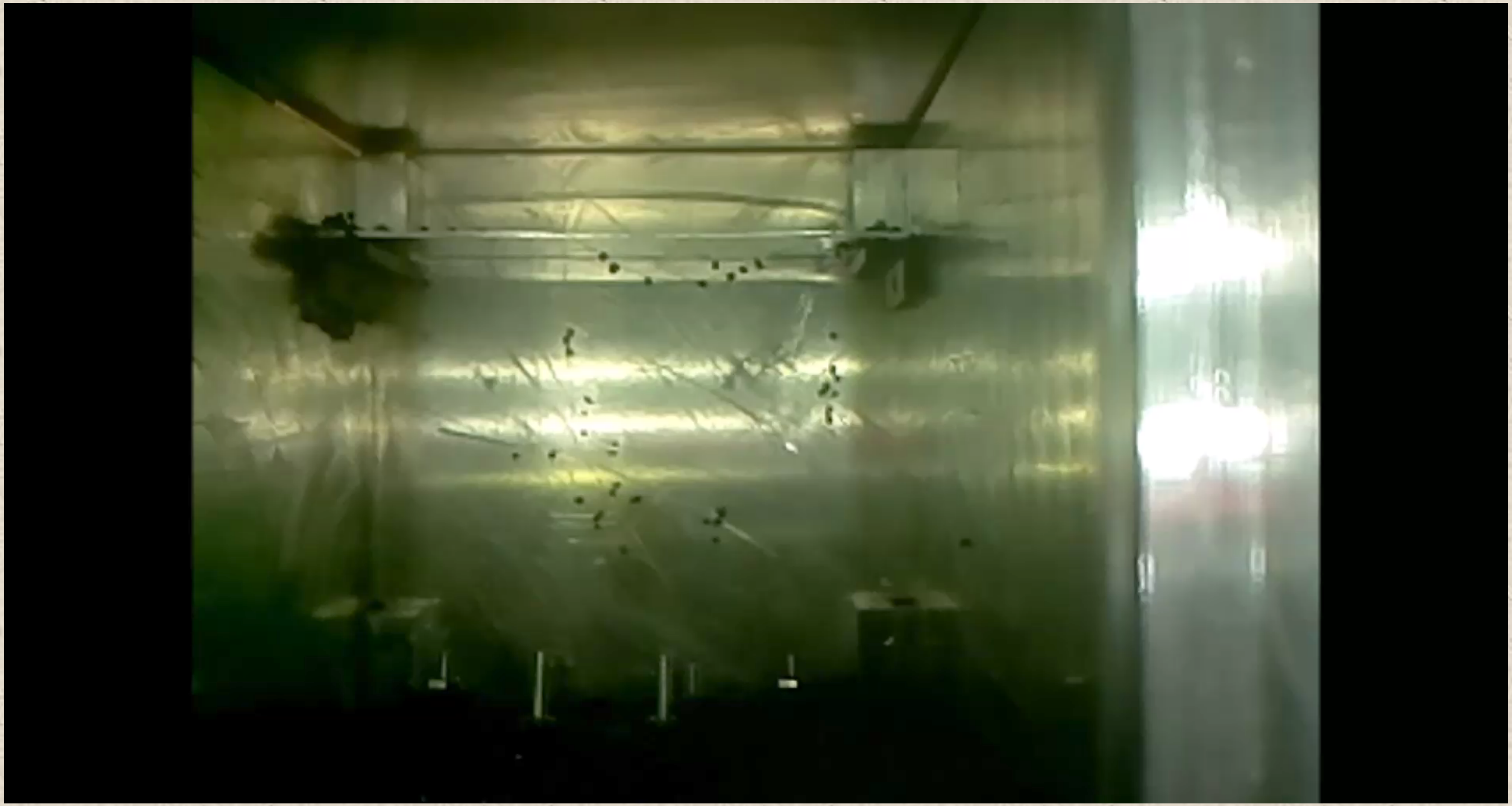
Engineering Model – Science Payload



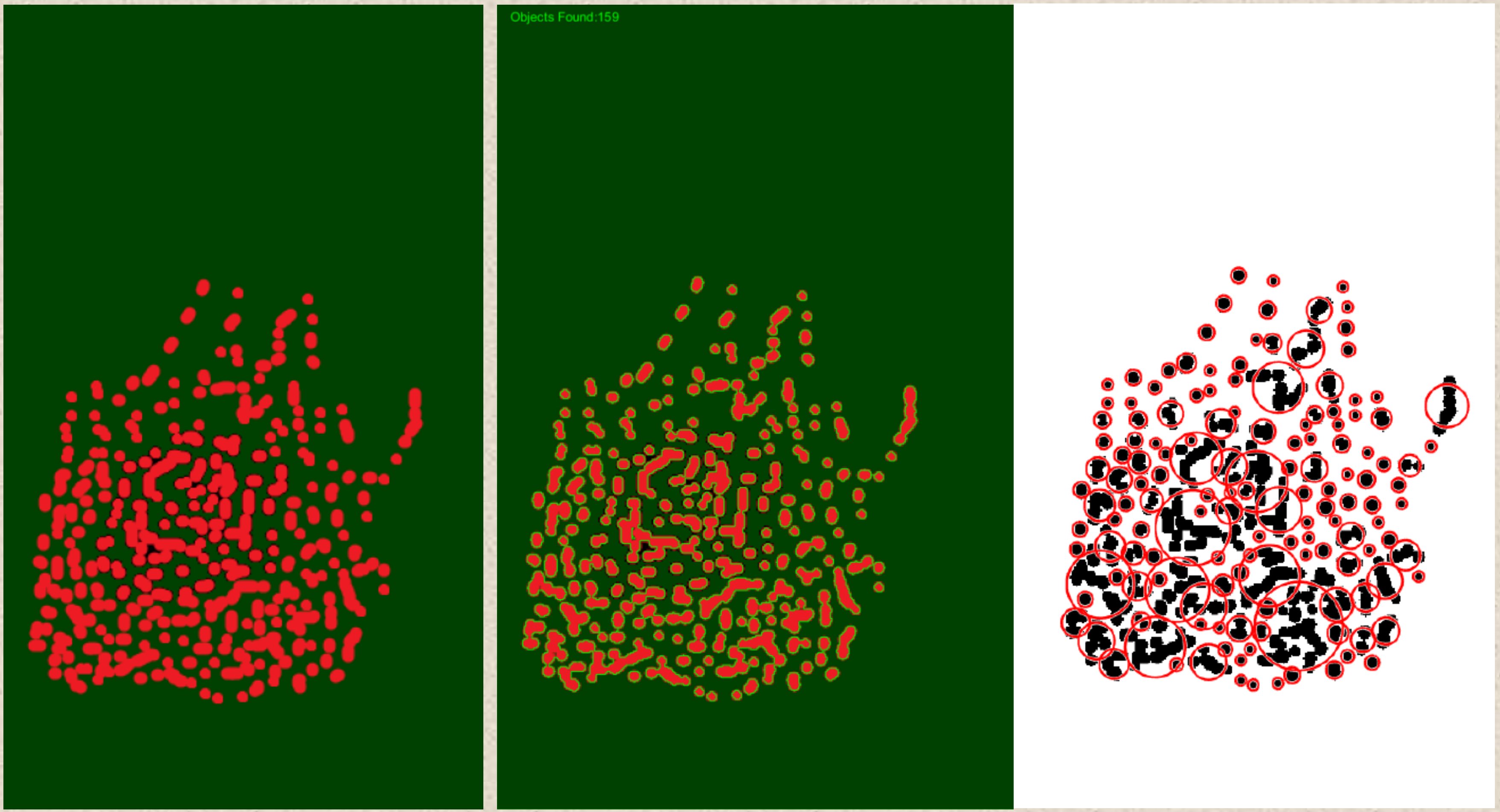
Engineering Model – Science Payload



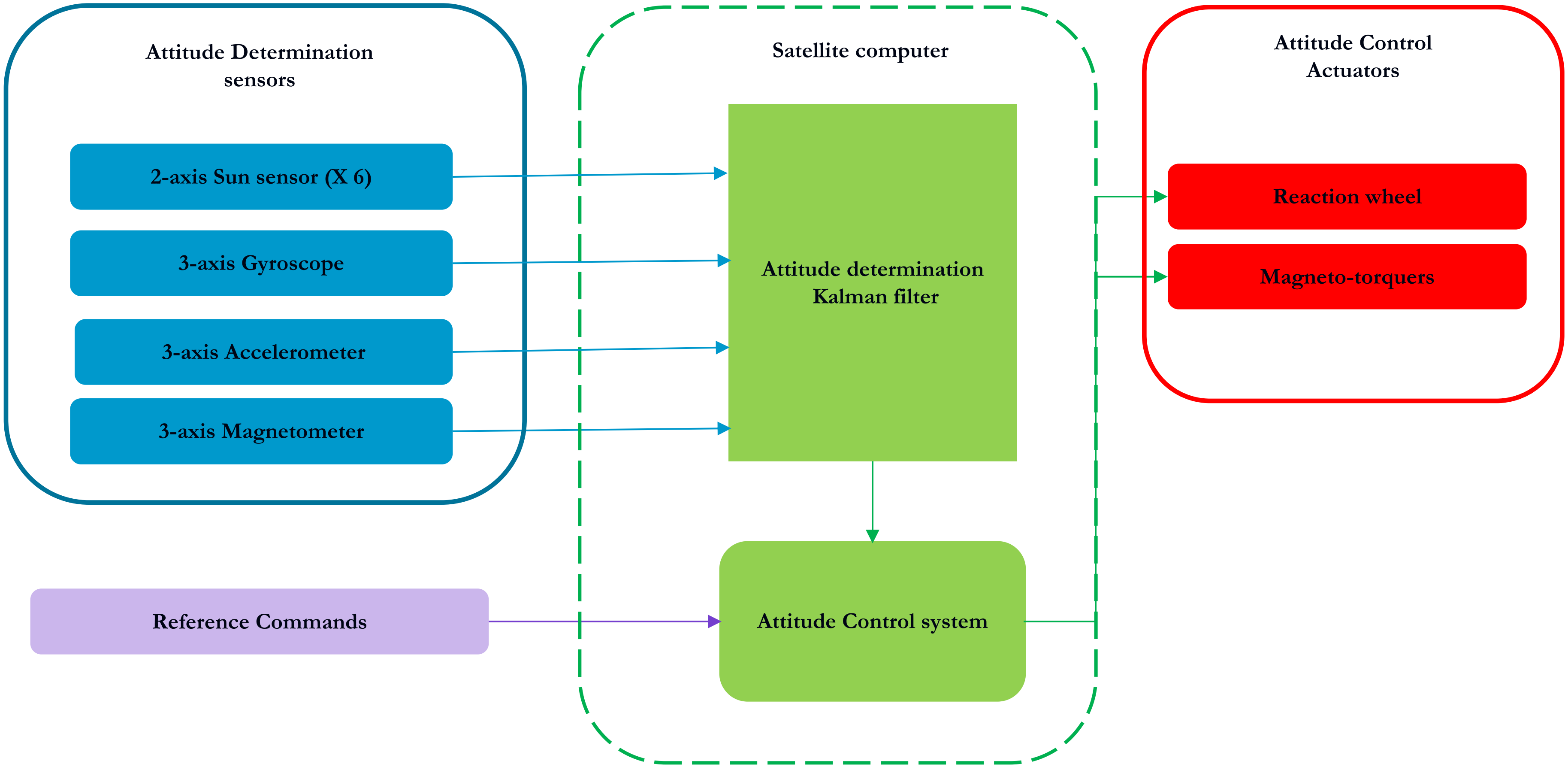
Engineering Model – Science Payload



Particle Detection and Statistics

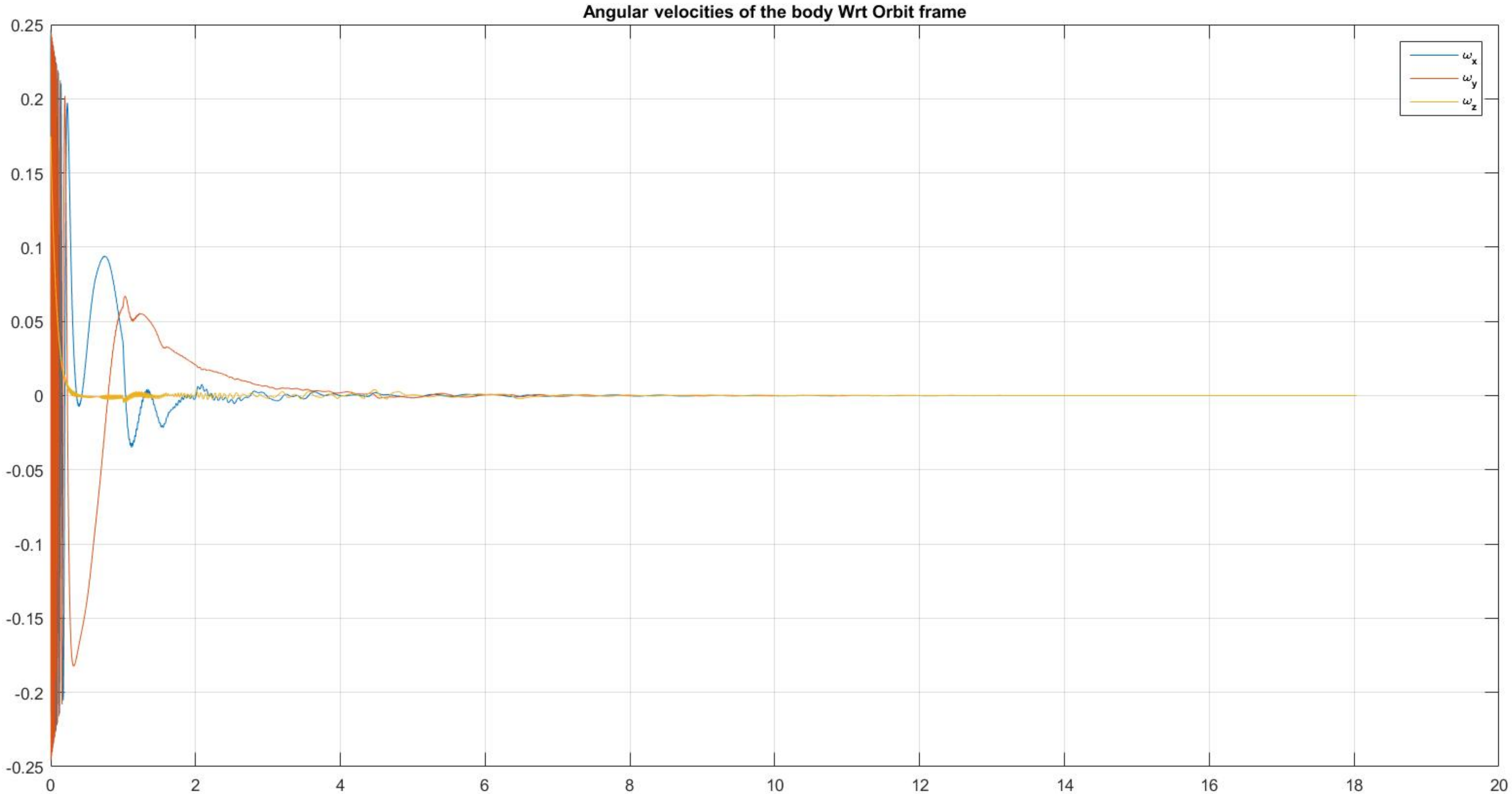


ADCS Subsystem



ADCS Layout

ADCS Results: Detumble and stabilize (Spin)



Angular velocities W.r.t orbit frame

Schedule

Event	Date
CDR	May 11, 2016
FRR	March, 2017
ORR	May, 2017
Launch Window Start	June, 2017

Launch and Operations

- Launch preference:
- Sun-synchronous orbit (800 km, 90.9 inclination)
- ISS orbit (375-400 km, 51.6 inclination)
  - Expect 1+ years of experiments and operations until decay out of orbit
- Operations:
  - Primary Mission: 1 month
  - Secondary Mission: 1 month
  - Tertiary Mission: 8 months+

AOSAT Team

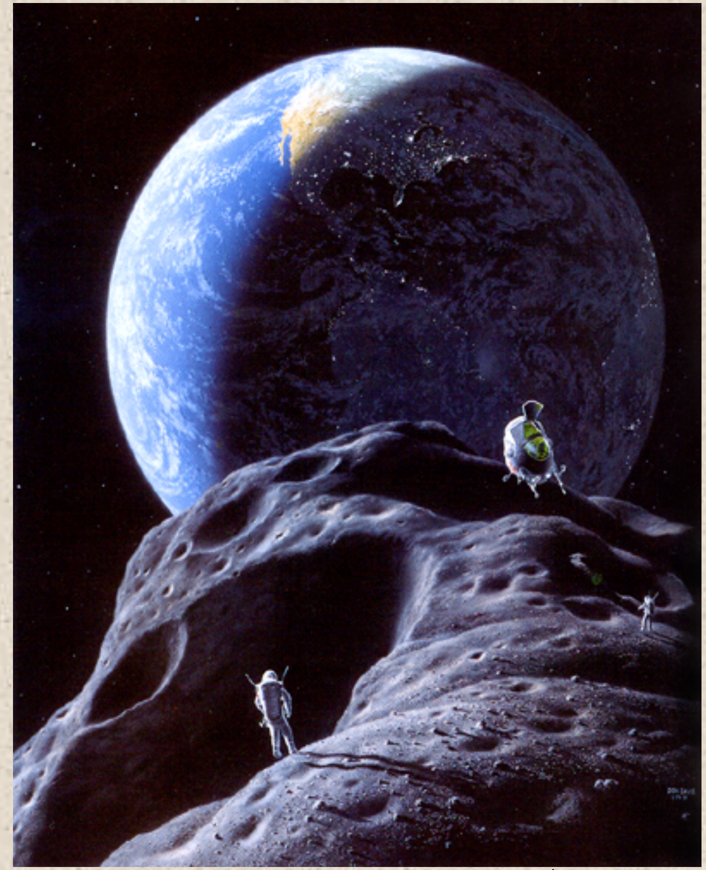
FACULTY:
- Erik Asphaug (Science PI)
- Jekan Thangavelautham (Engineering PI)

STUDENTS:
- Aman Chandra (Project Manager, Mechanical Systems)
- Andrew Thoesen (Mechanical Systems)
- Victor Hernandez (Electrical Power System)
- Andrew Warren (Electrical Power System)
- Laksh Raura (Electrical Power System)
- Ravi Teja Nallapu (ADCS)
- Akshay Choudhari (Communications)
- Salil Rabade (Thermal)
- Pranay Reddy (Software, CD&H)

REVIEW/ADVISORY BOARD:
- Dr. Andrew Klesh (Review Board Chair, Project Advisor, JPL)
- Prof. Christine Hartzell (Review Board, UMD)
- Prof. Daniel Scheeres (Review Board, CU)

Conclusions

- Asteroids, comets, small moons…
  - Are <u>not</u> zero gravity objects!
  - Their geology <u>depends</u> on gravity, even if only 0.0001 that of Earth
  - We can't design rovers and landers without answering basic questions:
    - Can I push on that?
    - Can I pick that up?
    - Can I anchor into that?
    - Can I move?
- Centrifuges inside of human-tended spacecraft are one possibility, but have never happened
- For milligravity, it's much easier to spin the whole spacecraft!



Don Davis / NASA