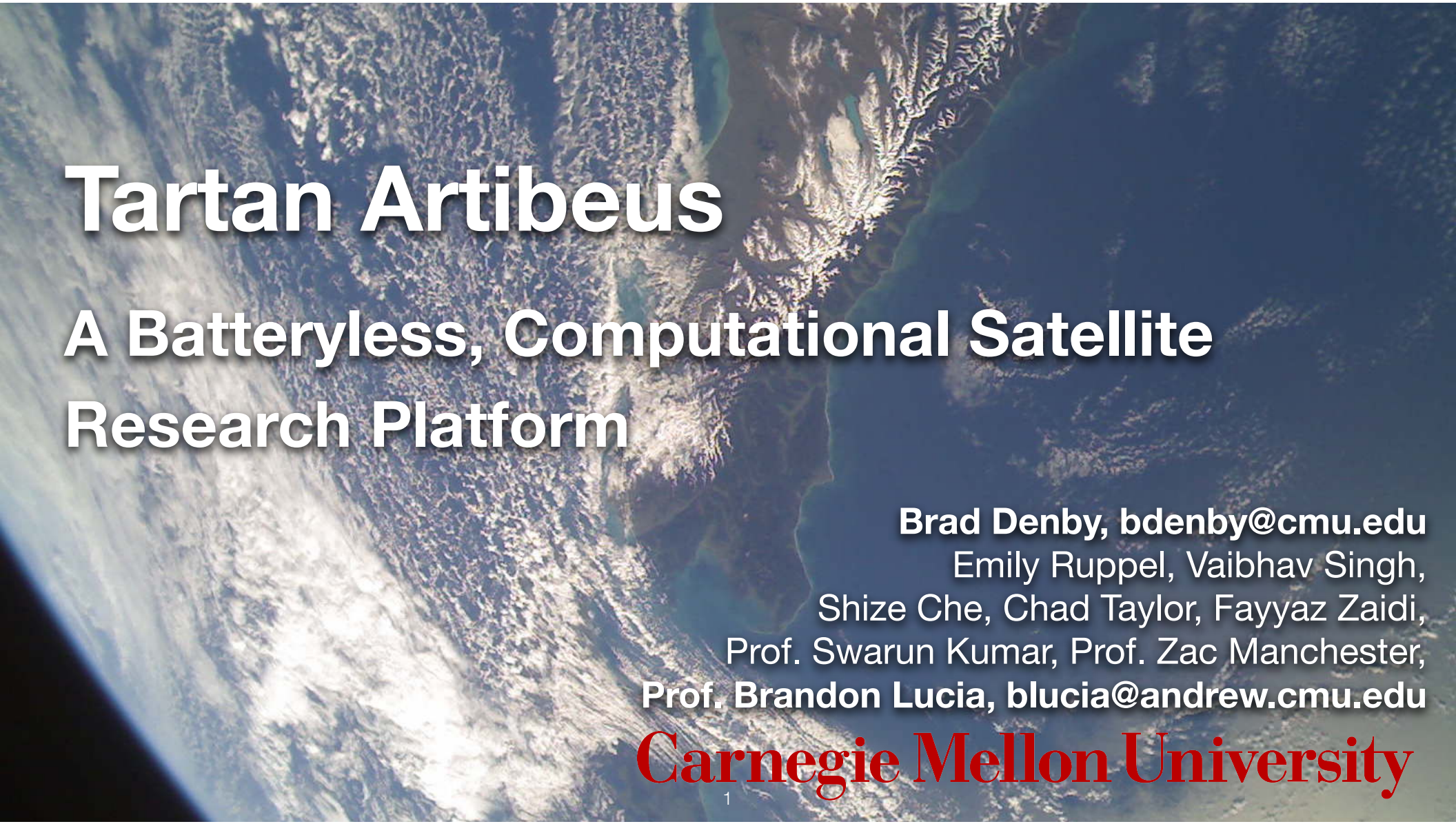
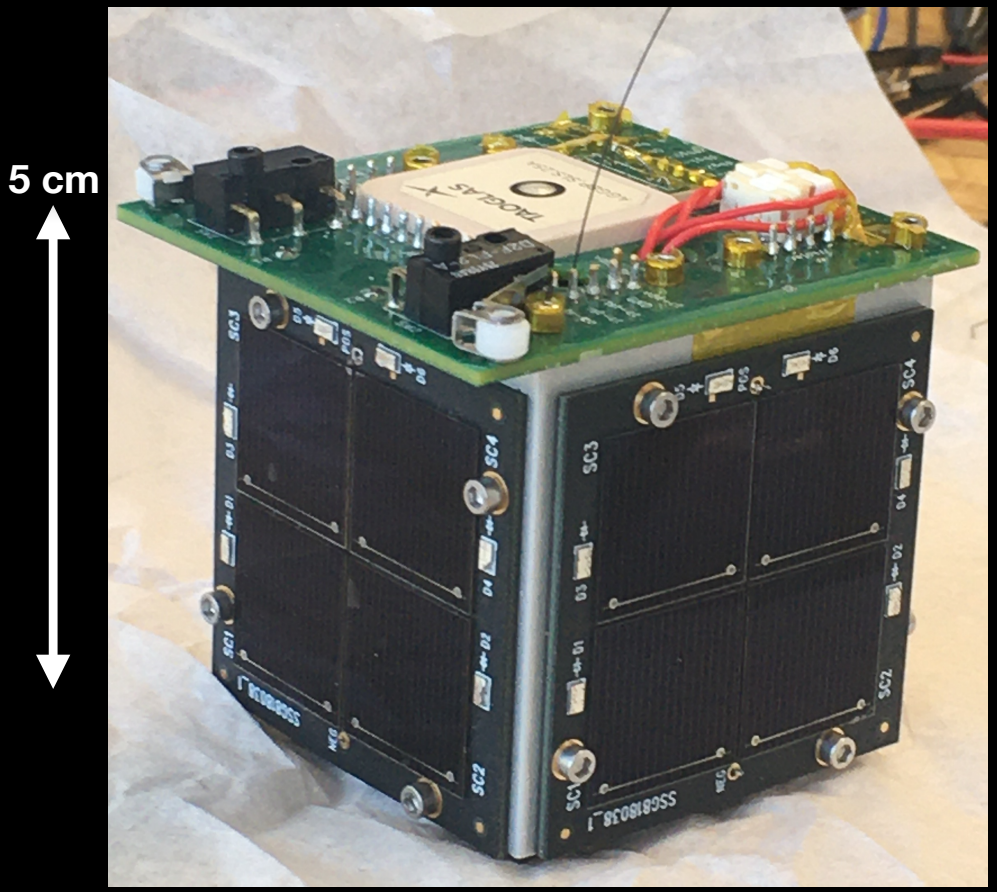


# Tartan Artibeus

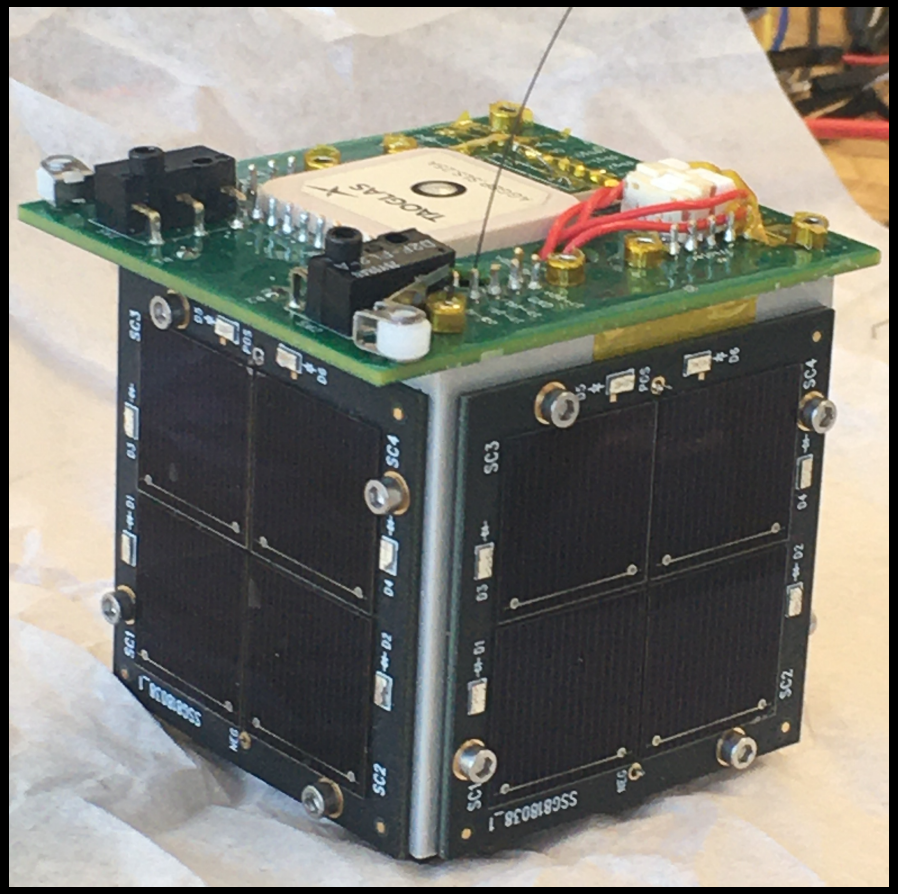
## A Batteryless, Computational Satellite Research Platform

**Brad Denby, bdenby@cmu.edu**
Emily Ruppel, Vaibhav Singh,
Shize Che, Chad Taylor, Fayyaz Zaidi,
Prof. Swarun Kumar, Prof. Zac Manchester,
**Prof. Brandon Lucia, blucia@andrew.cmu.edu**
Carnegie Mellon University

# Tartan Artibeus Pocketqube



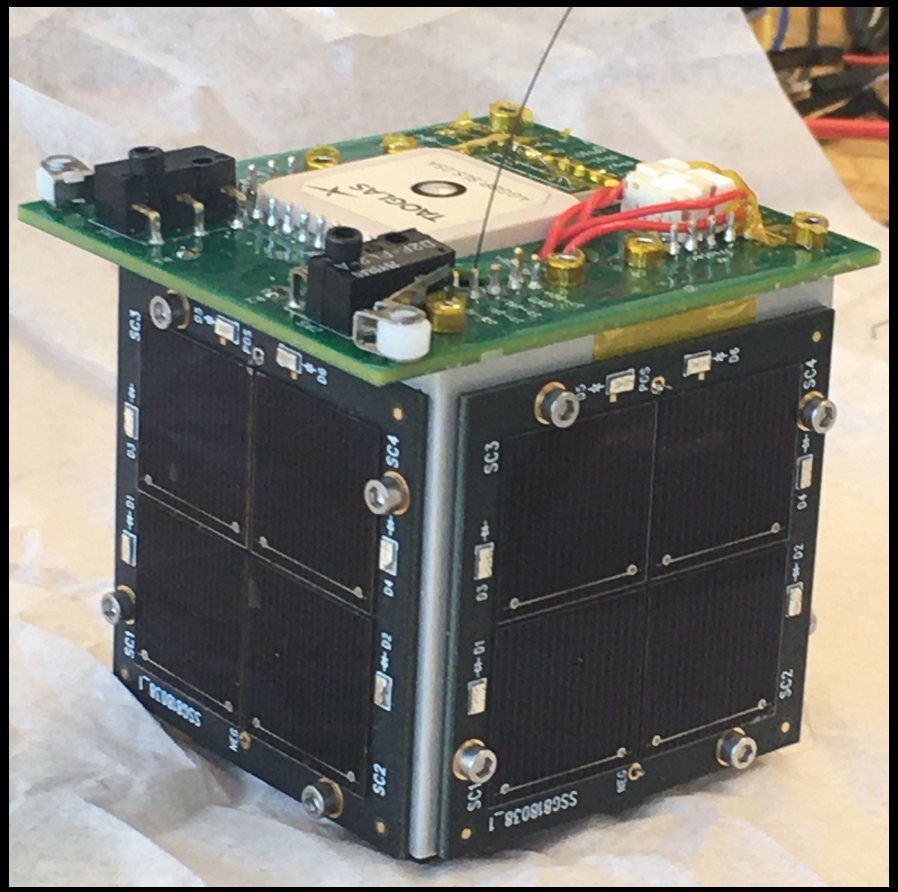
# Tartan Artibeus Pocketqube




## Goal 1: Accessible

**An open source platform ready to deploy to orbit**

# Tartan Artibeus Pocketqube



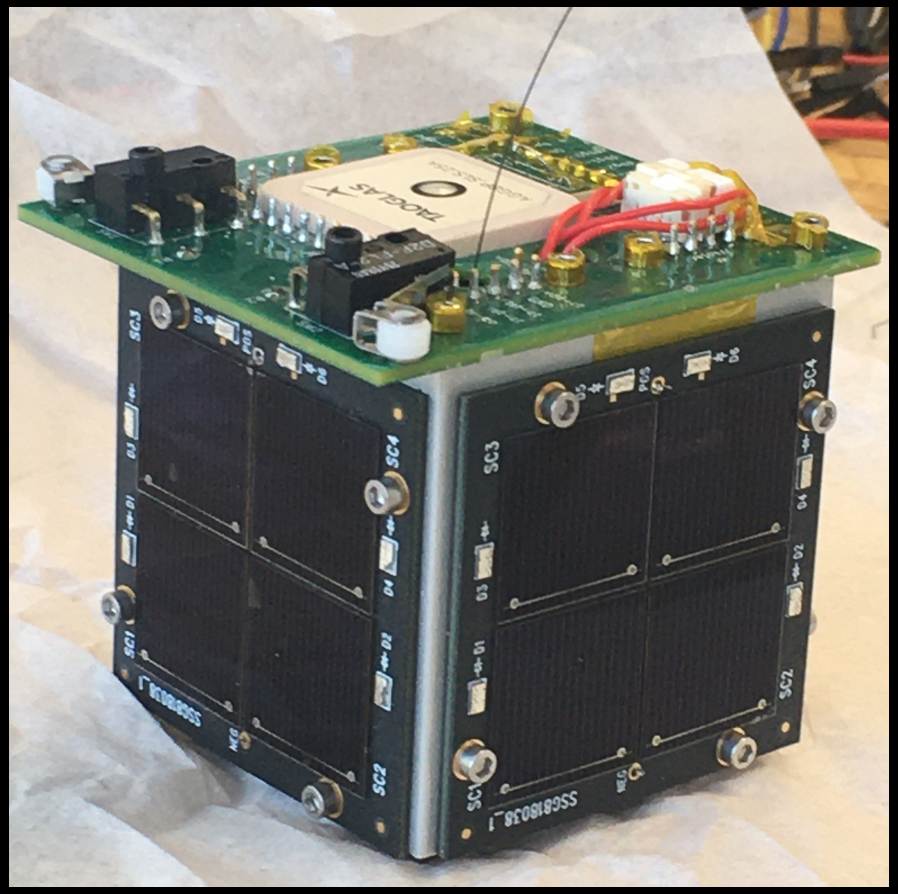

## Goal 1: Accessible

An open source platform ready to deploy to orbit

## Goal 2: Compatible

Connect with simulation software for mission planning

# Tartan Artibeus Pocketqube




## Goal 1: Accessible

An open source platform ready to deploy to orbit

## Goal 2: Compatible

Connect with simulation software for mission planning

## Goal 3: Extensible

Interface with computational modules for machine inference

# Overview

**The Next Ten Years of Low-Earth Orbit**

**Small Satellite Challenges & Opportunities**

**Our Focus: Orbital Edge Computing (OEC)**

**Tartan Artibeus Design and Implementation**

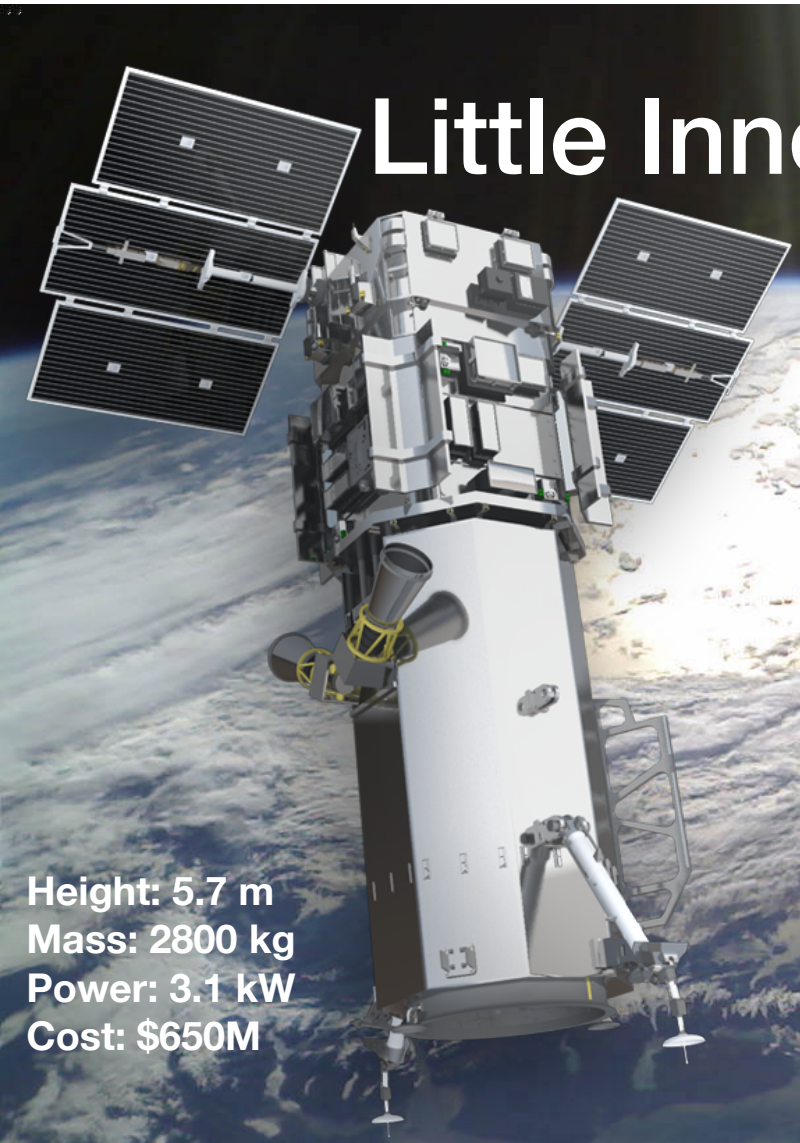
# Small Satellites Support Innovation

Height: 5.7 m
Mass: 2800 kg
Power: 3.1 kW
Cost: $650M

Height: 0.3 m
Mass: 4 kg
Power: 7.1 W
Cost: $65k

- Pocketqubes and Chip-scale Satellites

# Little Innovation in CONOPS



Height: 5.7 m
Mass: 2800 kg
Power: 3.1 kW
Cost: $650M

Command and Control

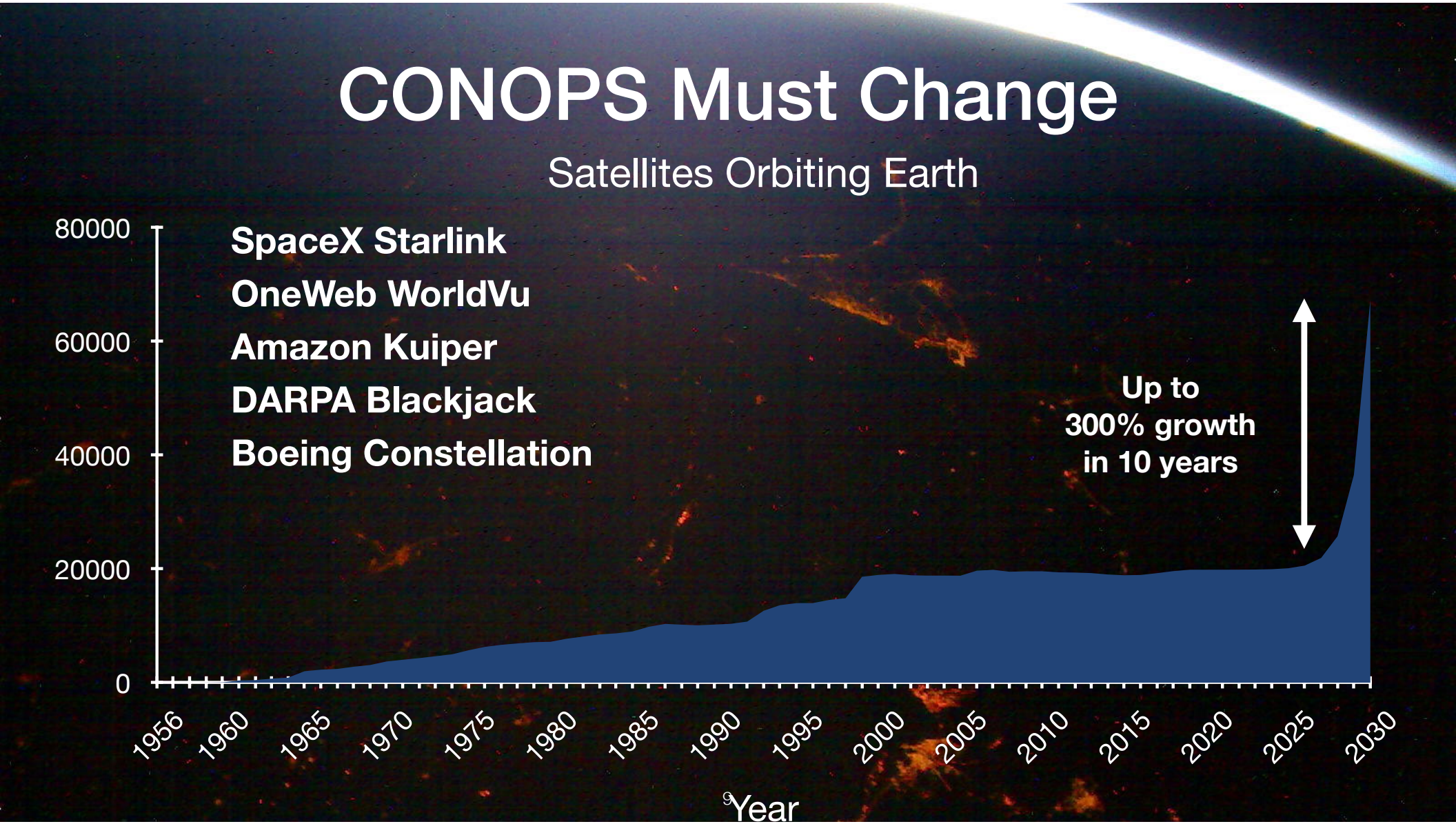
All Devices Share
a Bent-pipe CONOPS

Sensor Data

Height: 0.3 m
Mass: 4 kg
Power: 7.1 W
Cost: $65k

Pocketqubes and
Chip-scale Satellites

# CONOPS Must Change



# Overview

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**Small Satellite Challenges & Opportunities**

Our Focus: Orbital Edge Computing (OEC)

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# Downlinking Data Does Not Scale

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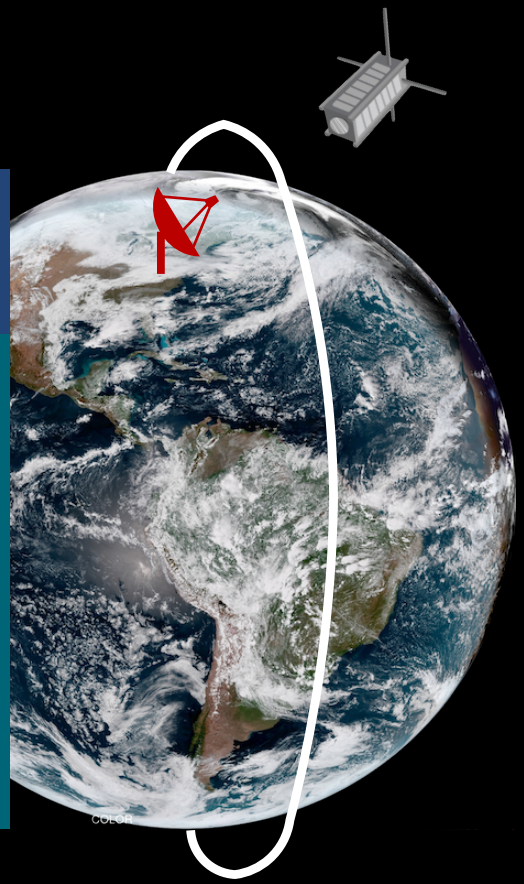
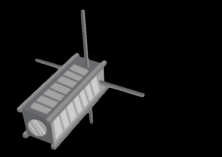
# Downlinking Data Does Not Scale

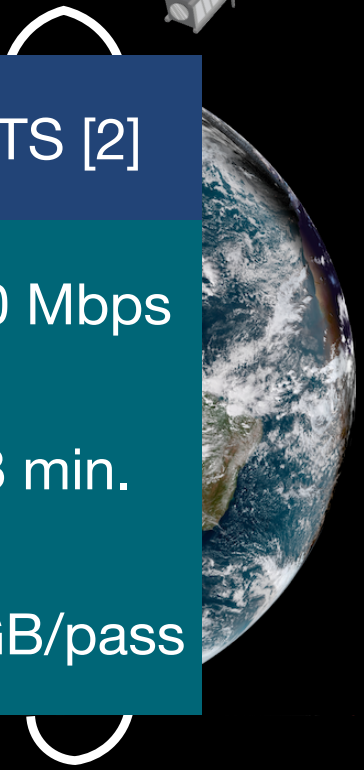
| | Enterprise [1] |
|---|---|
| Bitrate | 200 Mbps |
| TX Duration | <10 min. |
| Data Down | 15 GB/pass |



[1] Dove High Speed Downlink System

# Downlinking Data Does Not Scale





| | Enterprise [1] | COTS [2] |
|---|---|---|
| Bitrate | 200 Mbps | <120 Mbps |
| TX Duration | <10 min. | 7-8 min. |
| Data Down | 15 GB/pass | 5.3 GB/pass |

[1] Dove High Speed Downlink System

[2] `cote` Simulator: https://github.com/cmuabstract/cote

# Downlinking Data Does Not Scale

| | Enterprise [1] | COTS [2] | Near Future |
|---|---|---|---|
| Bitrate | 200 Mbps | <120 Mbps | 1 Gbps? |
| TX Duration | <10 min. | 7-8 min. | 10 min. |
| Data Down | 15 GB/pass | 5.3 GB/pass | 75 GB/pass |

[1] Dove High Speed Downlink System

[2] `cote` Simulator: https://github.com/cmuabstract/cote

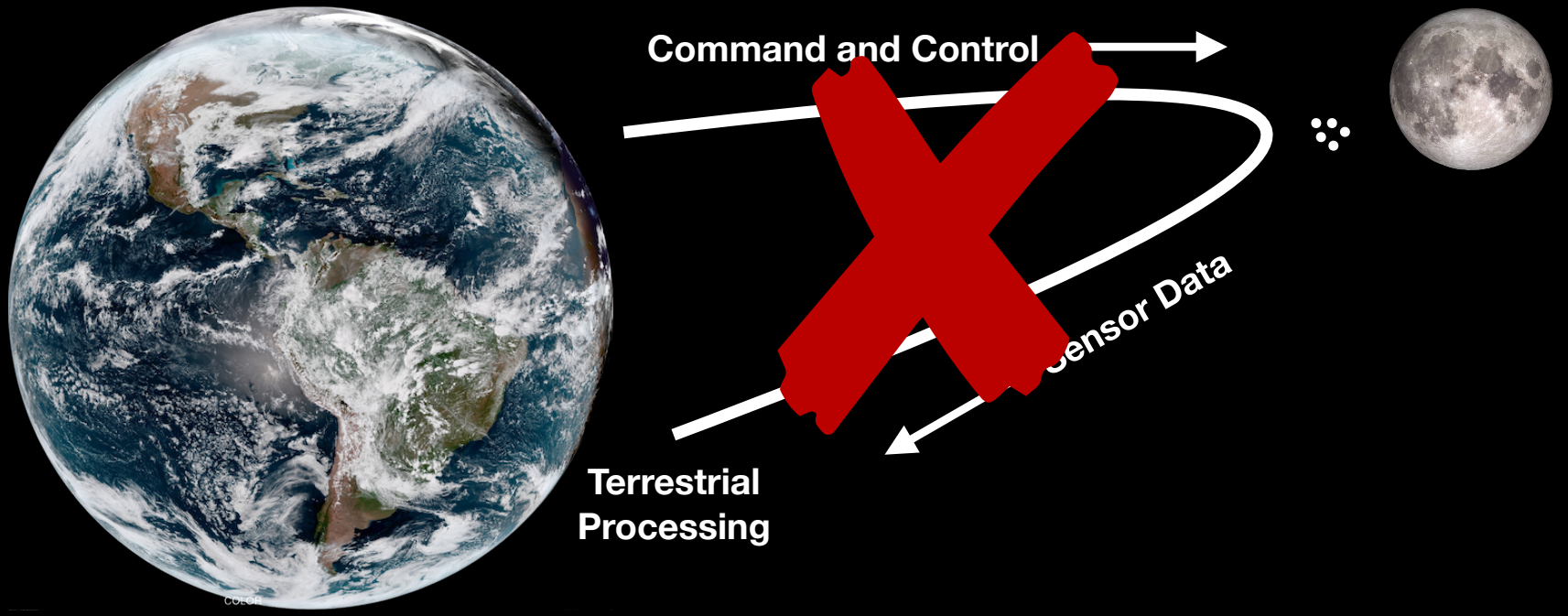
# Downlinking Data Does Not Scale

| | Enterprise [1] | COTS [2] | Near Future | Mega Constellation |
|---|---|---|---|---|
| Bitrate | 200 Mbps | <120 Mbps | 1 Gbps? | No Change |
| TX Duration | <10 min. | 7-8 min. | 10 min. | ↓(contention) |
| Data Down | 15 GB/pass | 5.3 GB/pass | 75 GB/pass | Less per sat. |

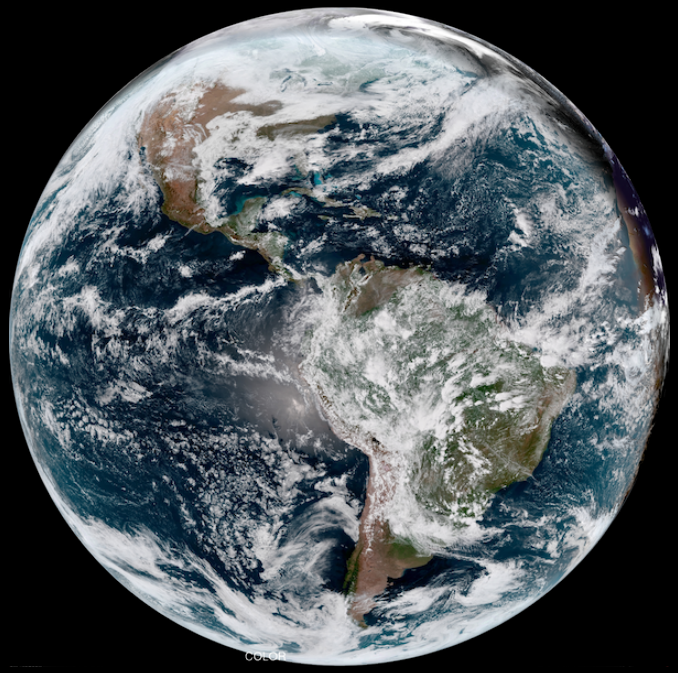
[1] Dove High Speed Downlink System

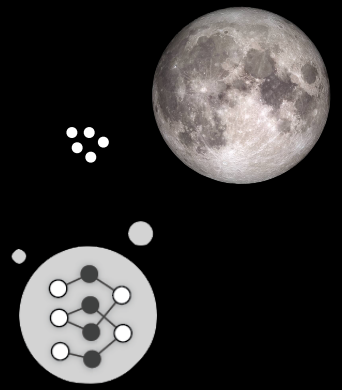
[2] `cote` Simulator: https://github.com/cmuabstract/cote

# Reducing Reliance on Bent Pipes



# Edge Computing: A Scalable Alternative

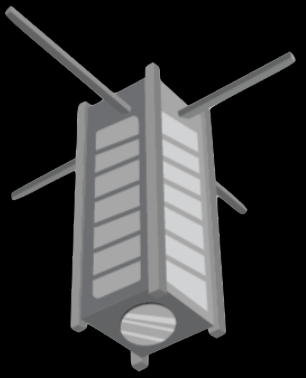




**Computing at the Edge**

# Edge Computing: A Scalable Alternative

**Existing Systems**



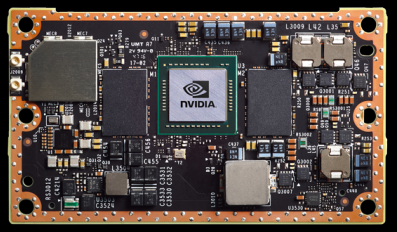
**Communication**

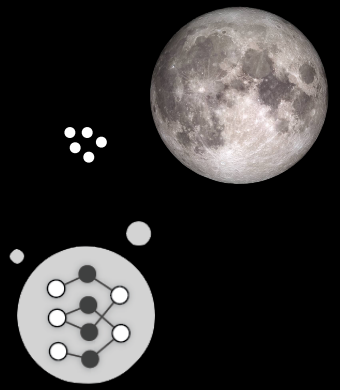
**Guidance, Navigation, & Control**

**Sensors**

**Edge Computing in Space**

**e.g. Embedded Compute Module**



**Computing at the Edge**

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# Computational Satellite Requirements

## Machine Learning in Space

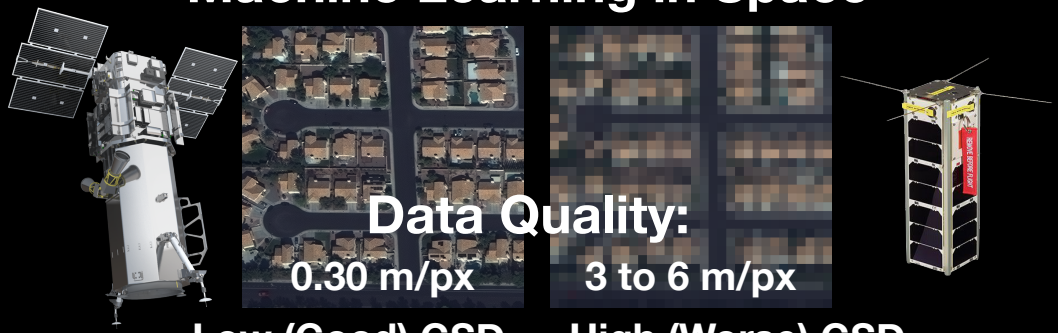

**Low (Good) GSD** **High (Worse) GSD**

## Machine Learning Bridges the Gap

*Orbital Edge Computing: Machine Inference in Space (CAL'19; B Denby, B Lucia)*

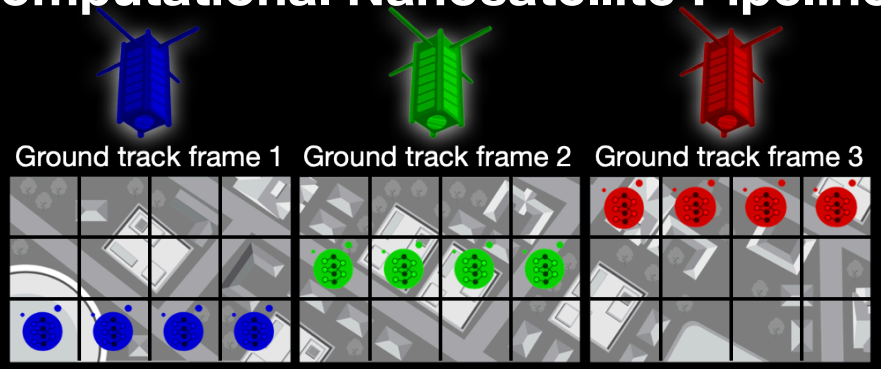
# Computational Satellite Requirements

## Machine Learning in Space




Low (Good) GSD  High (Worse) GSD

## Computational Nanosatellite Pipelines




## Machine Learning Bridges the Gap

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## Distributing Computation across Devices

*Orbital Edge Computing: Nanosatellite Constellations as a New Class of Computer System (ASPLOS'20; B Denby, B Lucia)*

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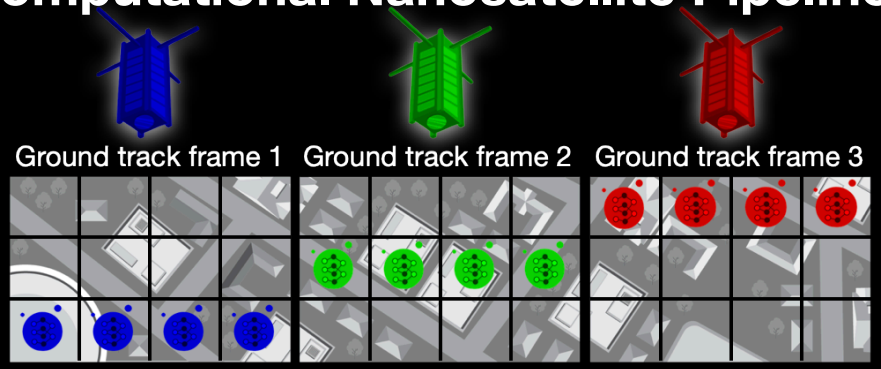
## Computational Nanosatellite Pipelines

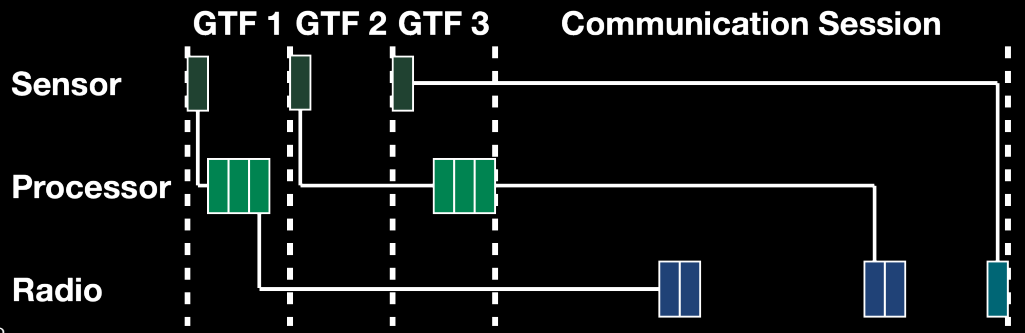



**Distributing Computation across Devices**

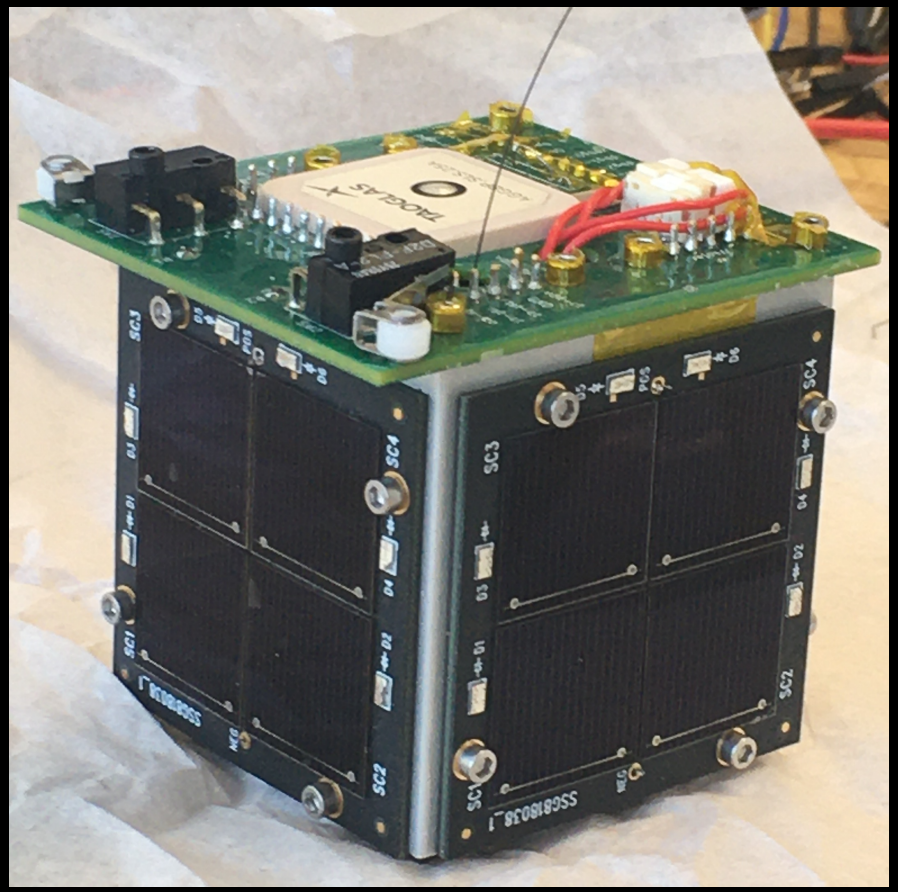
*Orbital Edge Computing: Nanosatellite Constellations as a New Class of Computer System (ASPLOS'20; B Denby, B Lucia)*

# cote: Open Source Orbital Edge Computing Simulator

*https://github.com/cmuabstract/cote*



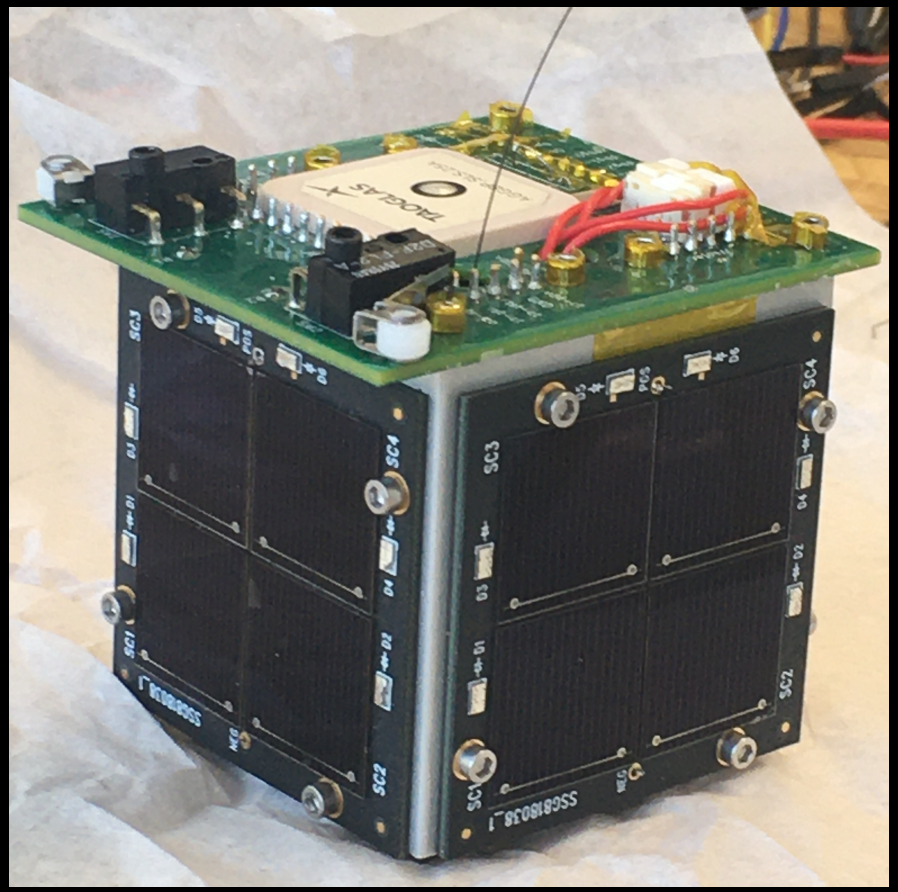
# Tartan Artibeus Pocketqube




**Goal 1: Accessible**

**Ground control of deployed satellites**

# Tartan Artibeus Pocketqube



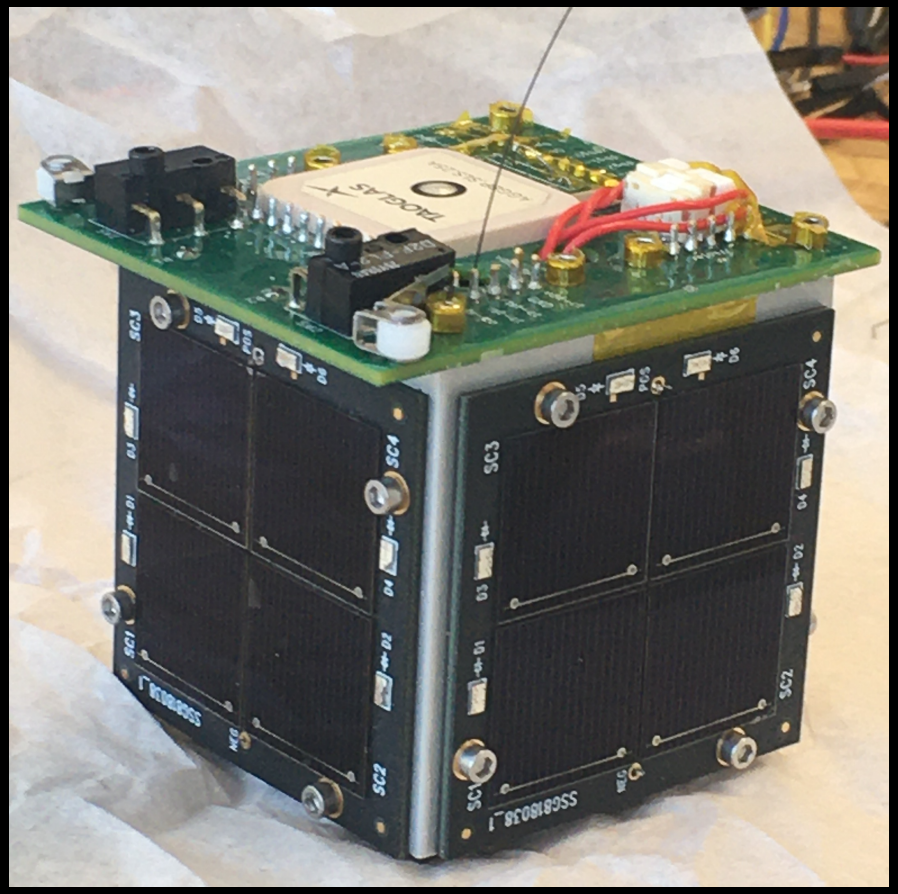

## Goal 1: Accessible

Ground control of deployed satellites

## Goal 2: Compatible

Hardware-in-the-loop simulation

# Tartan Artibeus Pocketqube




## Goal 1: Accessible

Ground control of deployed satellites

## Goal 2: Compatible

Hardware-in-the-loop simulation

## Goal 3: Extensible

Integration of third-party modules

# Overview

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Our Focus: Orbital Edge Computing (OEC)

**Tartan Artibeus Design and Implementation**

# Tartan Artibeus Bus (TAB)

TAB: a communication protocol for satellite data and commands

*https://github.com/cmuabstract/tartan-artibeus-sw*

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TAB: a communication protocol for satellite data and commands

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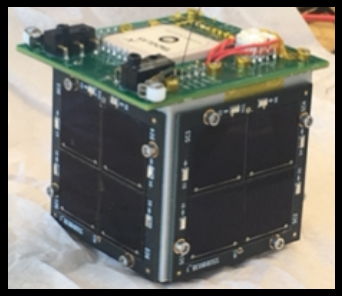
**Mission Simulation**

**Hardware in the Loop (Goal 2)**



**Flight Hardware**

# Tartan Artibeus Bus (TAB)

TAB: a communication protocol for satellite data and commands

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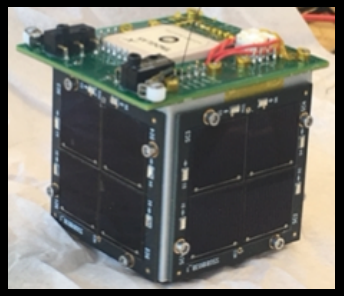
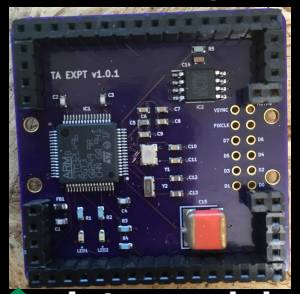
**Mission Simulation**

**Hardware in the Loop (Goal 2)**

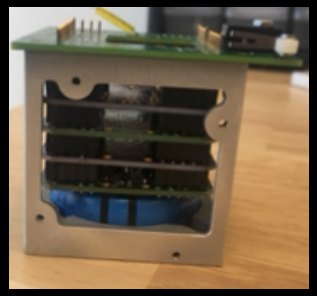


**Flight Hardware**

**Custom Payloads**




**Intermodule Communication (Goal 3)**



**Satellite Platforms**

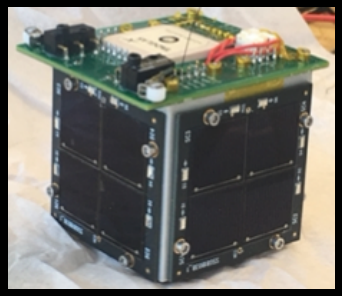
# Tartan Artibeus Bus (TAB)

TAB: a communication protocol for satellite data and commands

*https://github.com/cmuabstract/tartan-artibeus-sw*

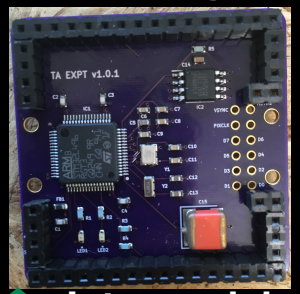
## Mission Simulation

Hardware in the Loop (Goal 2)

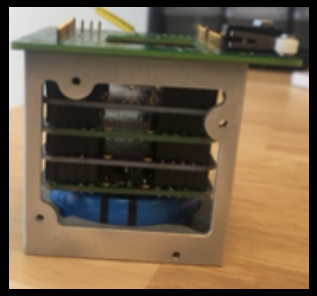


Flight Hardware

## Custom Payloads

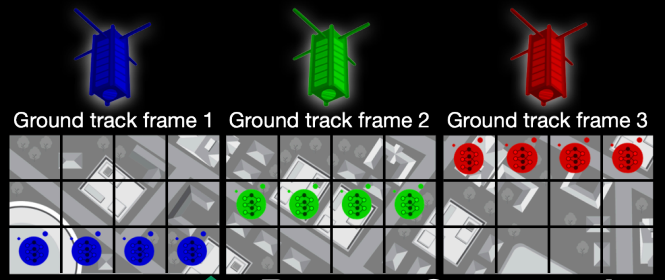



Intermodule Communication (Goal 3)

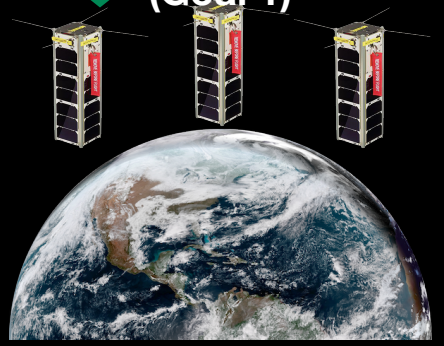


Satellite Platforms

## Research Concepts



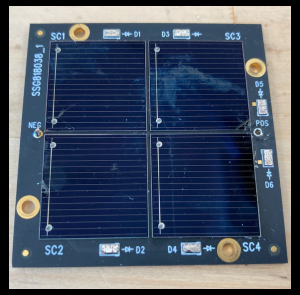

Remote Command and Control (Goal 1)

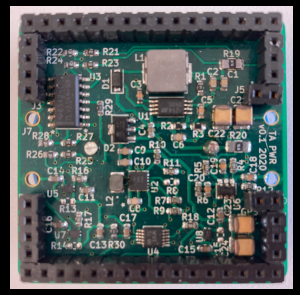


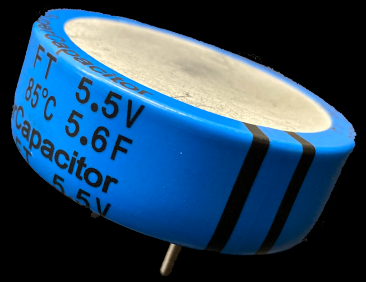
Deployment to Orbit

# Tartan Artibeus Satellite

## Energy System



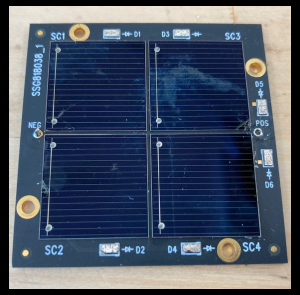



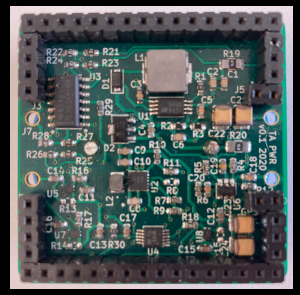


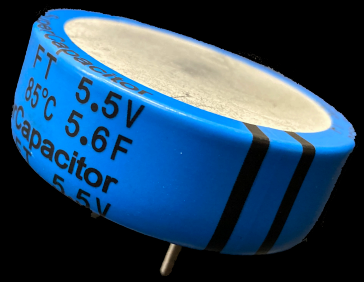

*https://github.com/cmuabstract/tartan-artibeus-hw*

# Tartan Artibeus Satellite

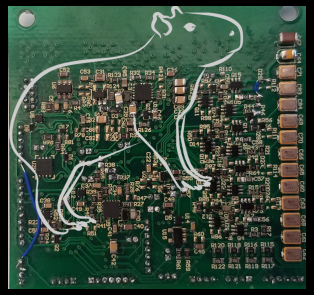
## Energy System








## Command and Control



*Capybara*

*Pocketqube C&DH*

*A reconfigurable energy storage architecture for energy-harvesting devices (ASPLOS'18; A Colin, E Ruppel, B Lucia)*

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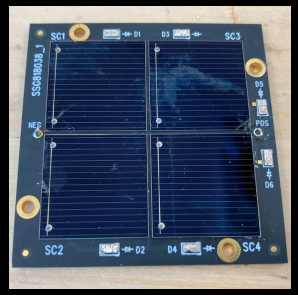
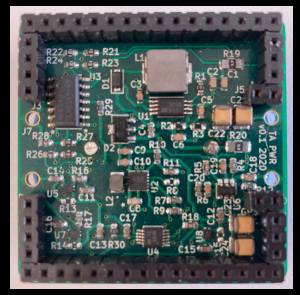
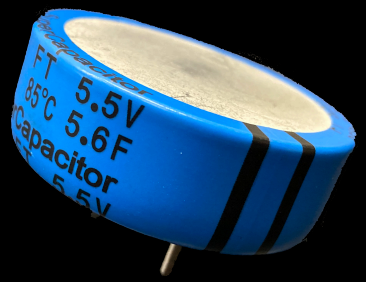
# Tartan Artibeus Satellite

## Energy System





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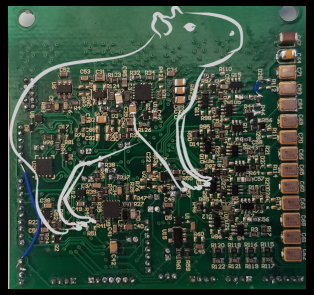

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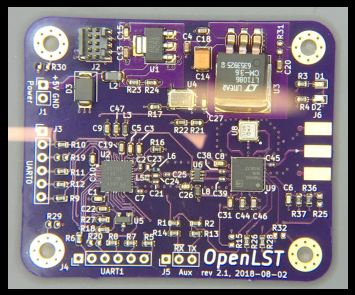
*Pocketqube C&DH*

*A reconfigurable energy storage architecture for energy-harvesting devices (ASPLOS'18; A Colin, E Ruppel, B Lucia)*

## Radio Communication




*OpenLST*


*Pocketqube Radio*

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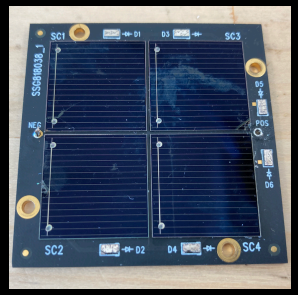
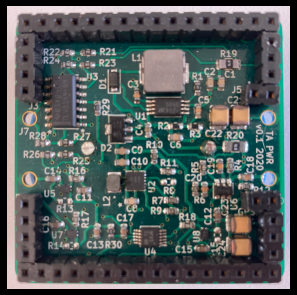
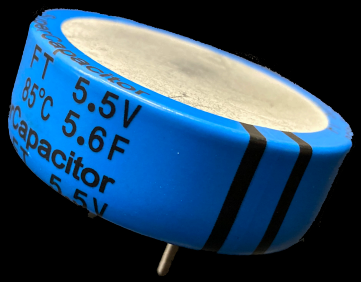
# Tartan Artibeus Satellite

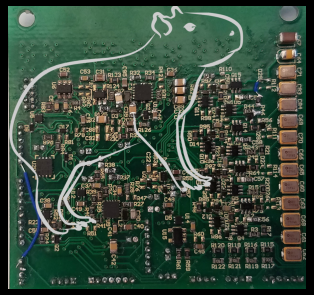
## Energy System








## Command and Control

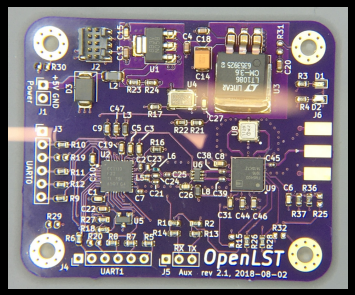


*Capybara*

*Pocketqube C&DH*

*A reconfigurable energy storage architecture for energy-harvesting devices (ASPLOS'18; A Colin, E Ruppel, B Lucia)*

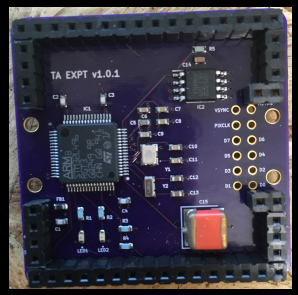
## Radio Communication




*OpenLST*


*Pocketqube Radio*

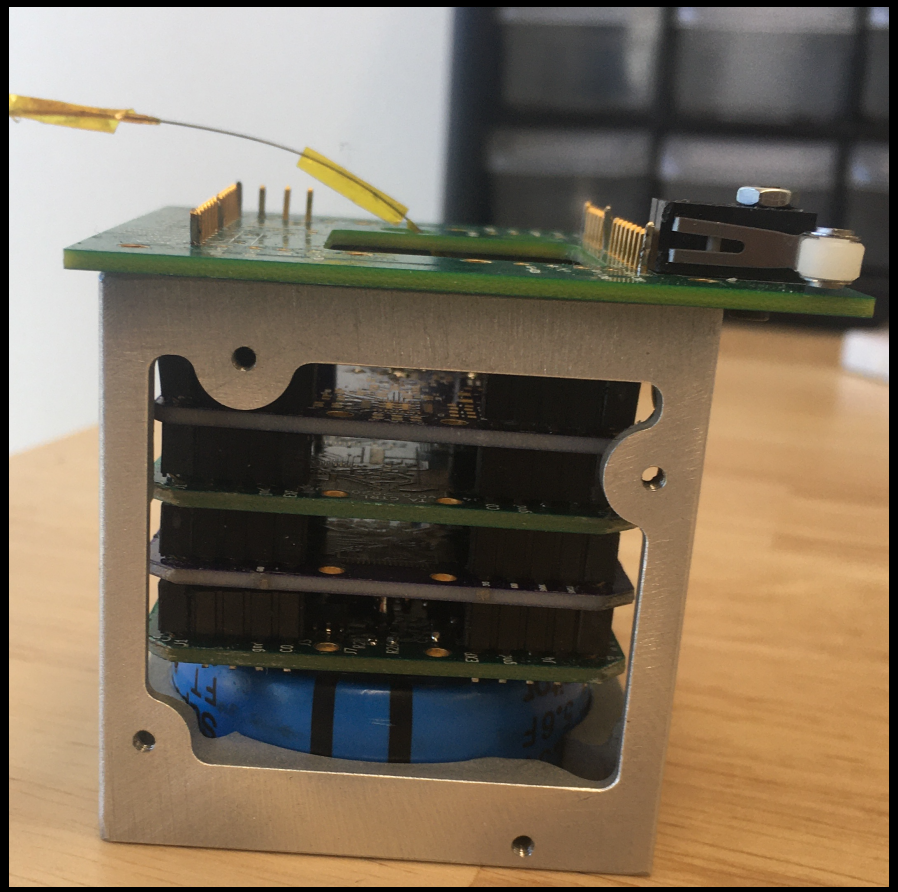
## Computational Payload

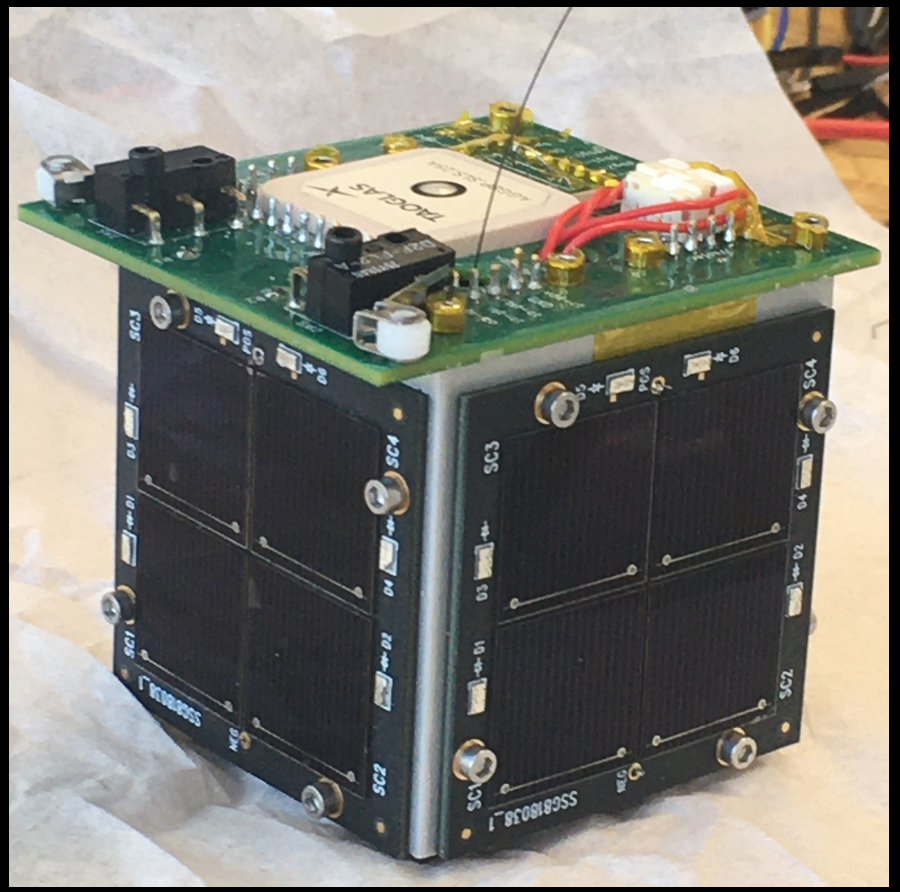



cote

*https://github.com/cmuabstract/tartan-artibeus-hw*

# Tartan Artibeus Pocketqube





Let's chat!

Message me at bdenby@cmu.edu to set up a meeting this week

Interested in graduate school?

Email Prof. Brandon Lucia at blucia@andrew.cmu.edu and visit our web page: http://abstract.ece.cmu.edu

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