The Any% Method: A Lessons Learned on Designing and Executing LeanSat Missions Quickly and Affordably

Bronco Space

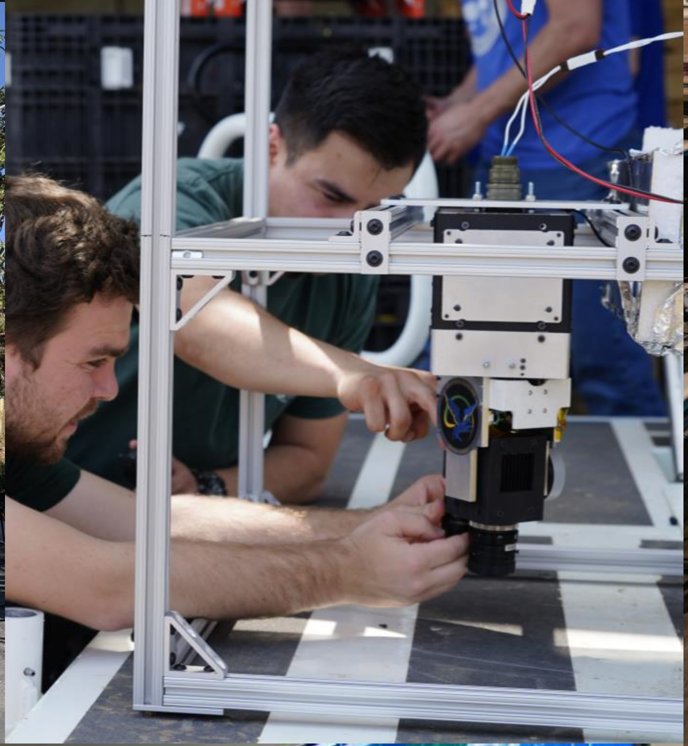
California State Polytechnic University, Pomona

For Public Release

February 13, 2024

About Bronco Space

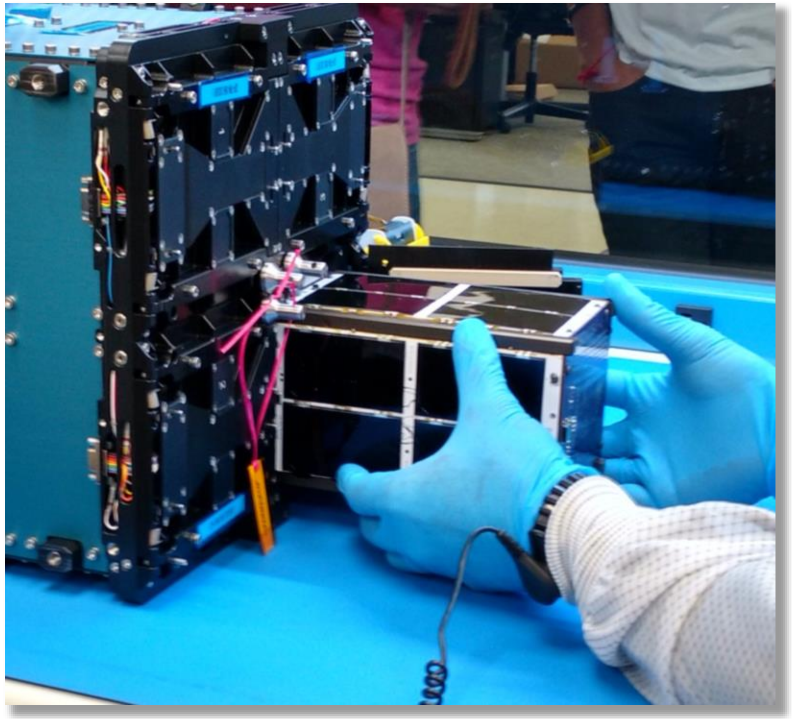
- Bronco Space is a mostly undergraduate student organization at Cal Poly Pomona.
- Founded in 2019, Bronco Space has run the entire gamut from starting at zero to becoming the leading space technology group at Cal Poly Pomona.
- Bronco Space has engaged in multiple NASA funded instrument development projects. Average time for TRL 3 to TRL 6 is 10 months.

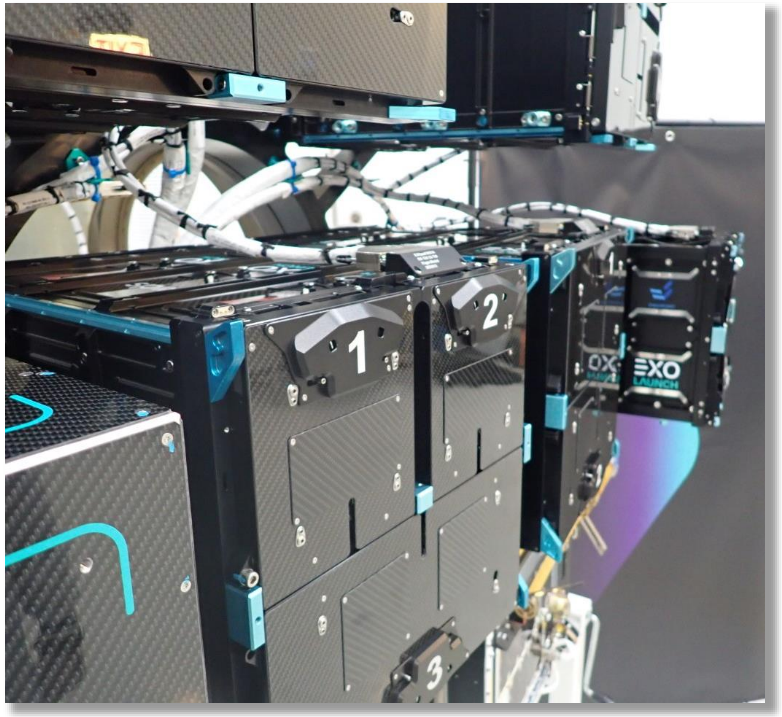





LAUNCHER

Bronco Space's Satellites





- In the last calendar year our organization has delivered three unique CubeSats for launch to LEO, all on commercial launch services. Our first CubeSat was launched in Summer 2022.
- The satellites have trended to be significantly cheaper and faster with each iteration.
- Our current effort is focused on PROVES (Pleiades Rapid Orbital Verification Experiment System).

BroncoSat-1 Mission Results

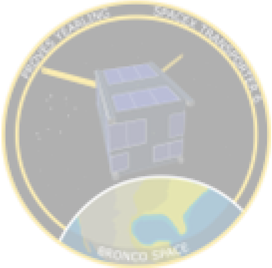
Mission Metrics

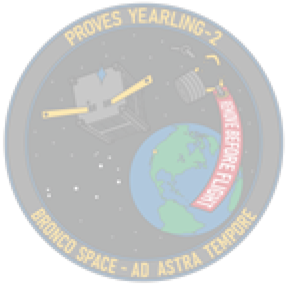
- **Mission Objective:** Artificial Intelligence and Machine Learning Technology Demonstration
- **Initial Planned Launch:** November 2021
- **Actual Launch:** June 2022 (Delay by Launch Provider)
- **Launch Result:** Dead on Arrival
- **Initial Budget:** $10k USD (Not Including Launch)
- **Actual Cost:** $120k USD (Not Including Launch)

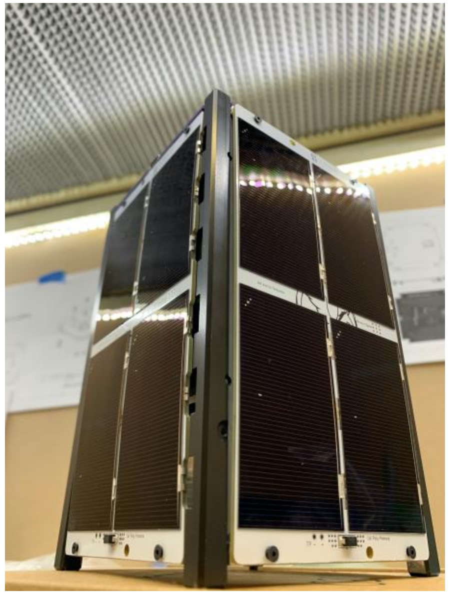
Key Lessons Learned

- Do not trust performance claims from COTS vendors without independent validation.
- Closed source and non-transparent designs are not conducive to an academic project.
- It is possible to deliver a CubeSat with very little in person involvement if properly managed.

BroncoSat-1

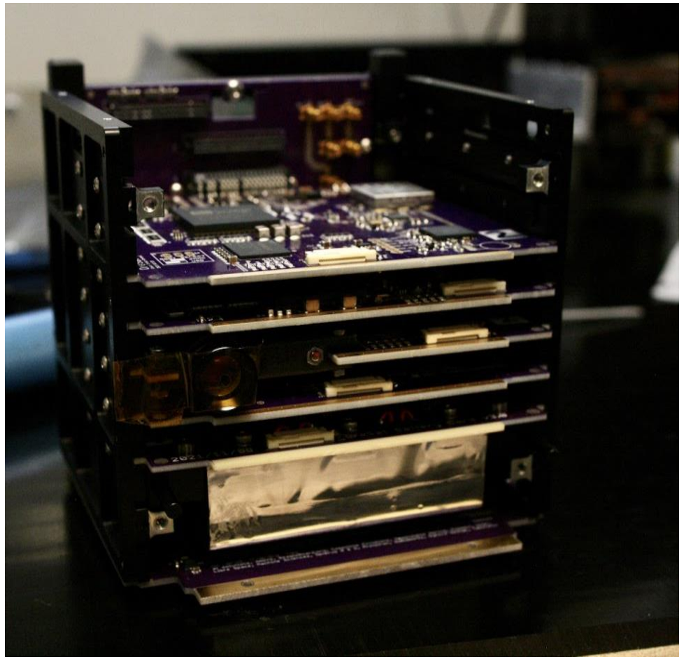






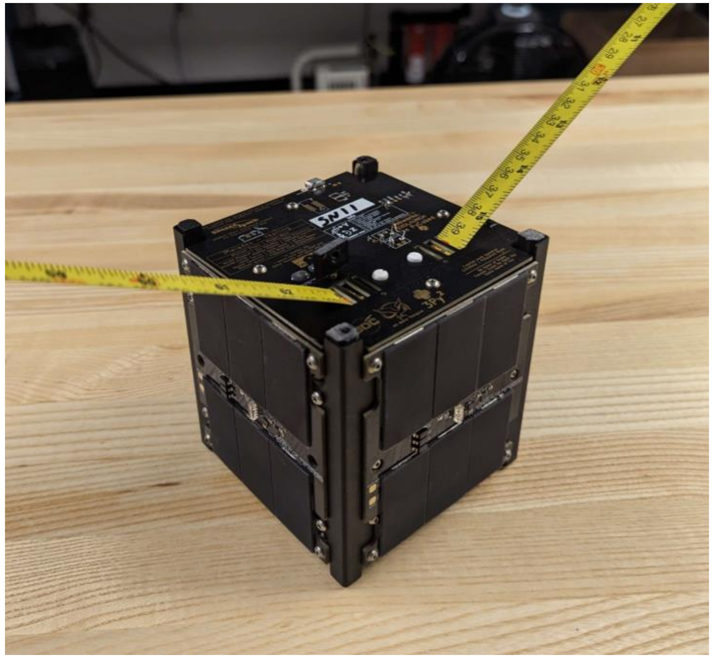
The Three US Open Source CubeSat Platforms

OreSat



- Modular Card Cage System
- OreSat Power Domain and Backplane are unique features
- Resilient but high cost

PyCubed / PROVES



- Single Board Computer architecture
- Minimal overhead is the goal
- Less resilient but very low cost

Artemis CubeSat

- Most traditional CubeSat architecture
- PC104 stackup and Raspberry Pi
- Heavily supported by NASA

Pleiades – Yearling 1 Mission Results

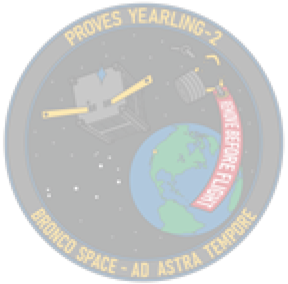
Mission Metrics

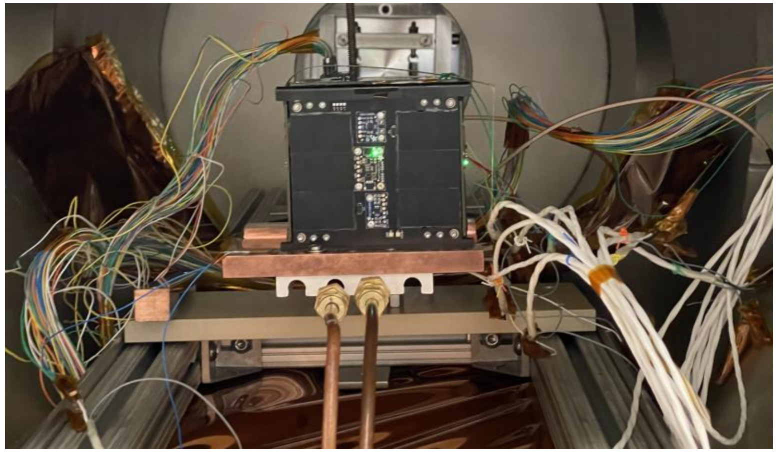
- **Mission Objective:** Flight Validation of PROVES Kit & Intersatellite Link Demonstration
- **Initial Planned Launch:** October 2022
- **Actual Launch:** January 2023 (Delay by SpaceX)
- **Launch Result:** Failure to Deploy (OTV Failure)
- **Initial Budget:** $35k USD (Including Launch)
- **Actual Cost:** $48k USD (Including Launch)

Key Lessons Learned

- Supply chain must be a key consideration during the parts selection process.
- Try to chose readily available parts that also have the smallest learning curve for the team.
- Trust but verify performance of the launch provider, especially if they are a new provider.

Yearling - 1






Pleiades – Yearling 2 Mission Results

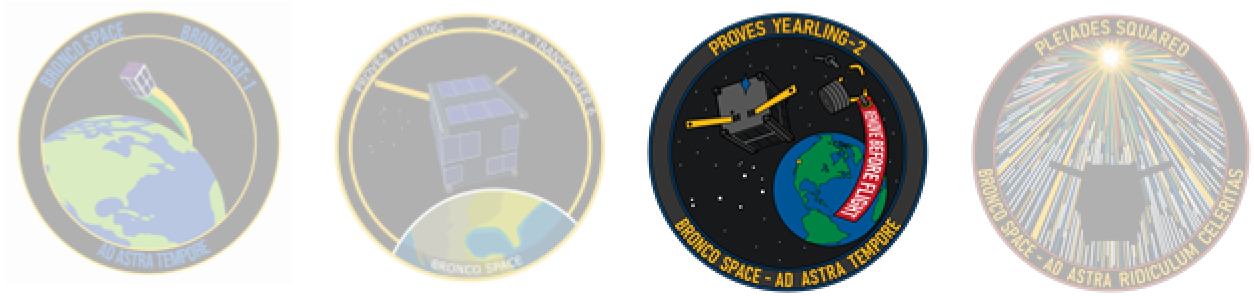
Mission Metrics

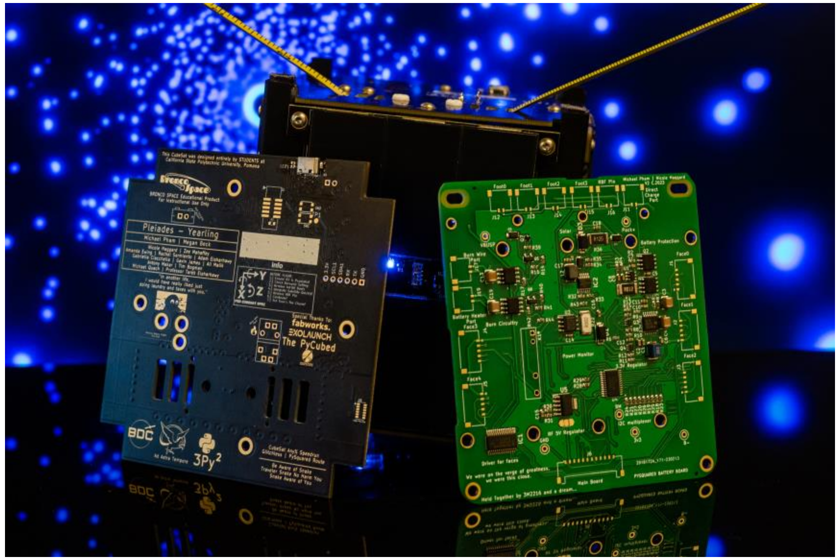
- **Mission Objective:** Flight Validation of PROVES Kit & Intersatellite Link Demonstration
- **Initial Planned Launch:** NET Fall 2023
- **Actual Launch:** April 2023
- **Launch Result:** Initial Telemetry | Early Loss
- **Initial Budget:** $30k (Including Launch)
- **Actual Cost:** $32k (Including Launch)

Key Lessons Learned

- ”Think slow, act fast” design philosophy works very well for rapid iteration of designs.
- Parallel workflows are essential to quick design, build, test, fix loops.
- Responsive and fast early mission ops is extremely important. Utilize global community networks whenever possible.

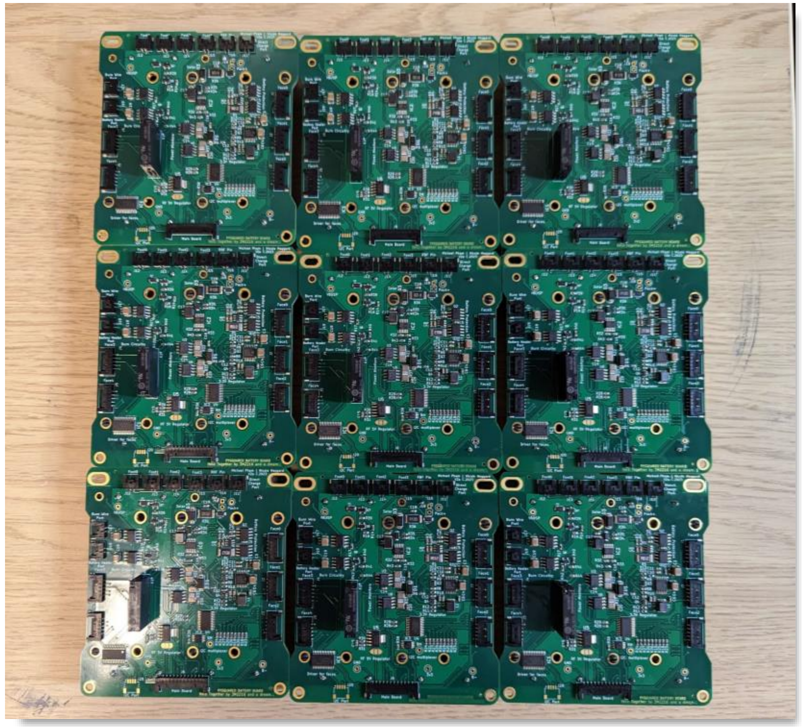
Yearling - 2





Design for Mass Manufacturing

- Sheet metal structure for faster manufacturing.
- Enforcing conformity to simpler designs rather than enabling complexity.



- Single sided PCBs that could be quickly SMT assembled and with parts already at the board house.
- Completed sub-assemblies can be binned for quality.

- Multiple iterations to actively fix issues that slowed integration
- Batch manufacturing to maximize experience carry over and parallelism

Pleiades – Squared Mission Results

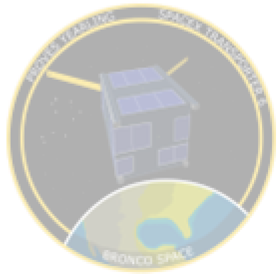
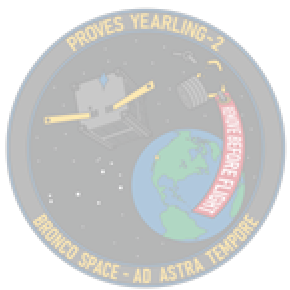
Mission Metrics

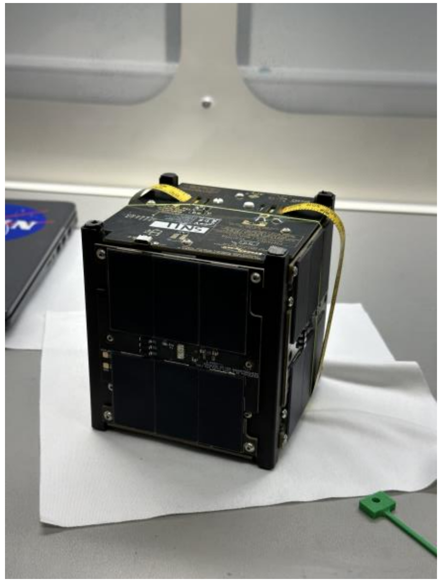
- **Mission Objective:** Rapid Response CubeSat Delivery Demonstration
- **Initial Planned Launch:** NLT 2024
- **Actual Launch:** June 2023
- **Launch Result:** Full Mission Data | Early Loss
- **Initial Budget:** $30k (Including Launch)
- **Actual Cost:** $26k (Including Launch)

Key Lessons Learned

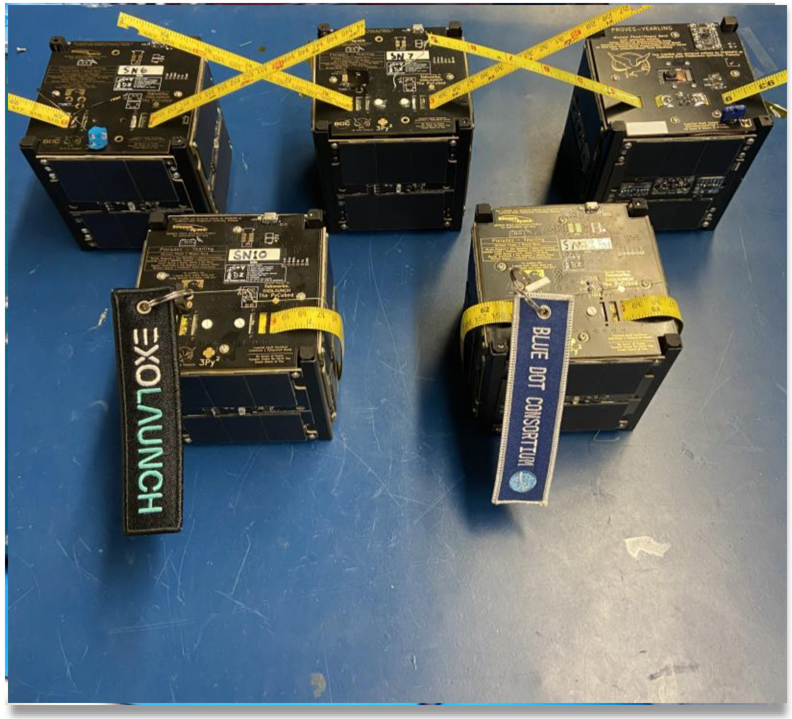
- Pre-stocked and binned components allow for can allow for extremely fast delivery.
- Repeated experience with integration and test procedures net very large gains in efficiency.
- Prepare extra operational contingencies during early mission in case of launch provider mishap.

Pleiades - Squared



The PROVES Kit



- 21 PROVES Serial Numbers assigned as of February 2024
- Another 5 builds are in progress at various partner organizations.
- Currently there are 8 university users of the PROVES Kit and 2 high school users.

Radiation Testing

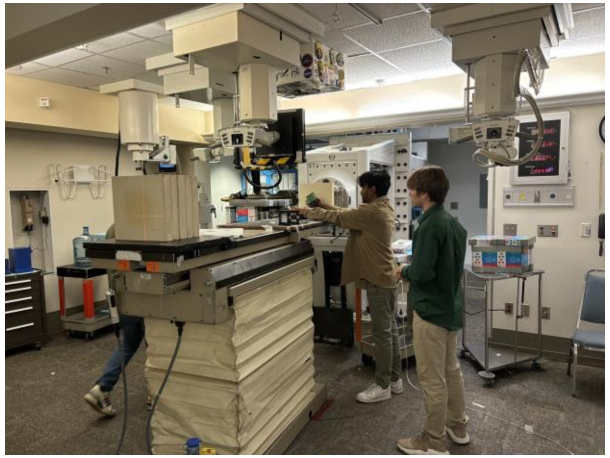
Key Points For Radiation Testing

- **Objective**
  - To investigate the Polar Low Earth Orbit radiation effects of the electronics of the PROVES Flight Controller (FC) Board
  - Protons and Heavy Ions are the particles of concern in this orbit
  - Recently irradiated the FC board with High Energy Protons to observe single event effects

Key Lessons Learned

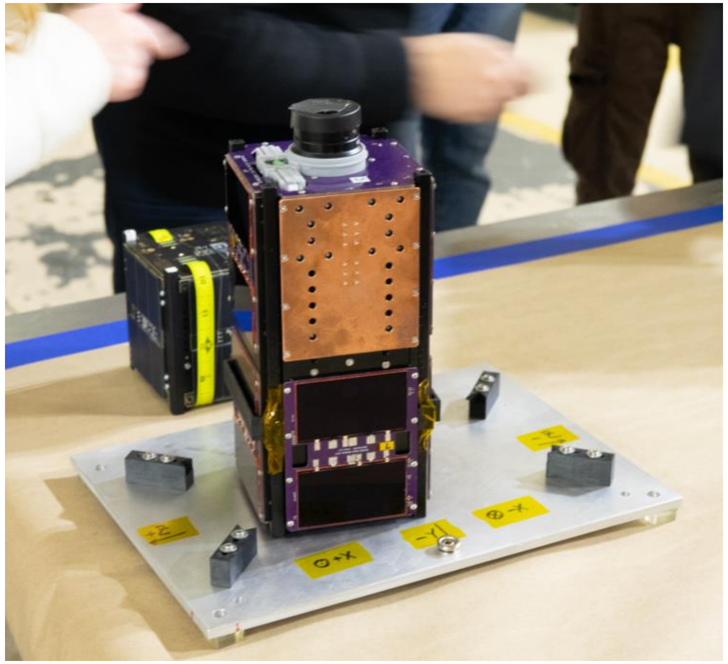
- The Flight Controller Board encountered numerous non-destructive single-event effects
- Practice runs of setting up the test setup before the date of testing will help in being efficient with time at the facility
- Provides valuable educational experience for aspiring

Testing at Loma Linda



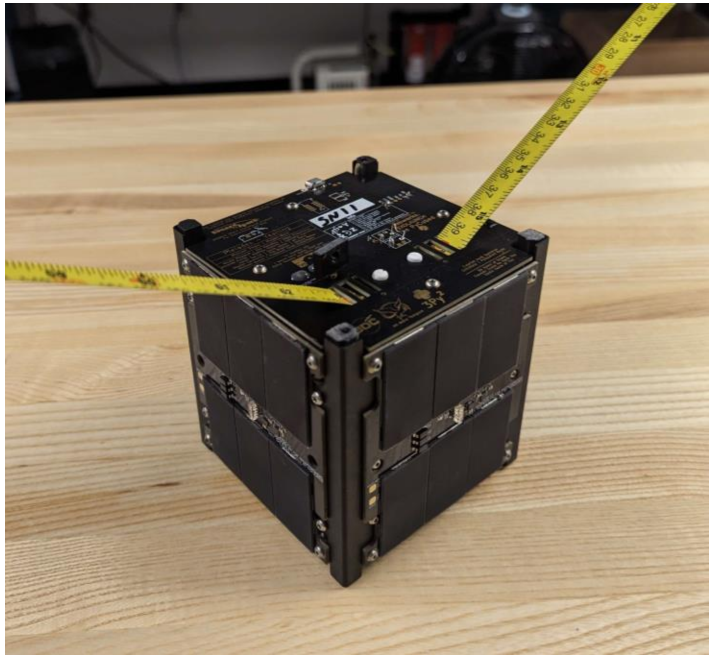
Upcoming Satellite Missions

OreSat-0.5



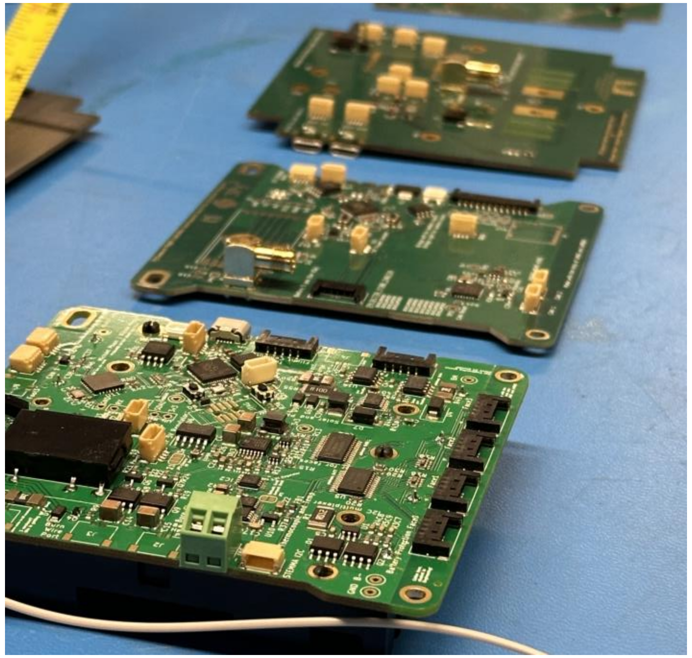
- Fully Open Source ADCS
- DxWiFi High Speed 2.4Ghz Data Link
- Launch on SpaceX TR11

Pleiades - Orpheus



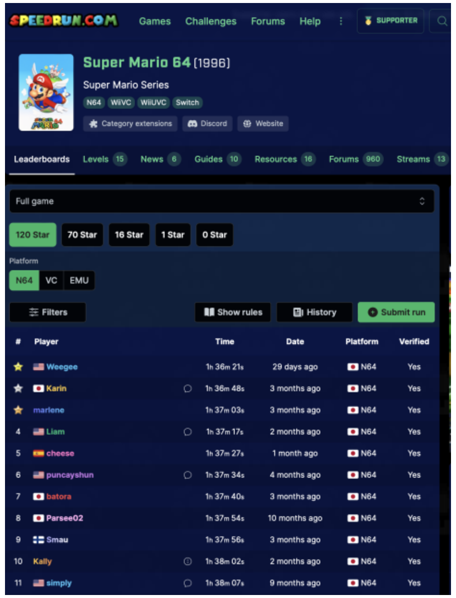
- Additional validation for the PROVES Kit
- Built by High School Students
- Launch on SpaceX TR11

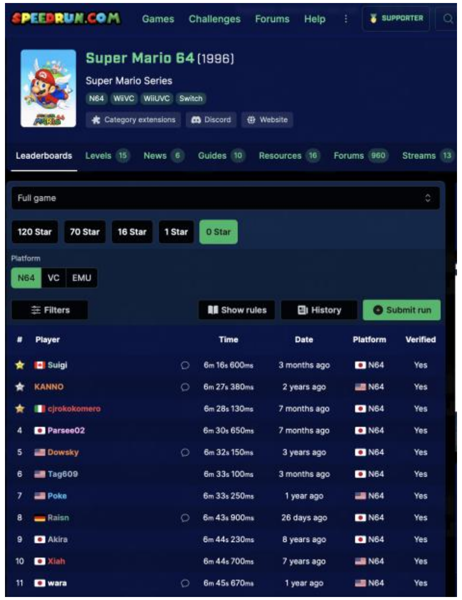
Pleiades - Cerberus



- Testing COPPER
- COmmon Payload Plate for Expedited Research
- Launch NET Summer 2024

Any% Speed Running and Lean Satellites





Source: speedrun.com

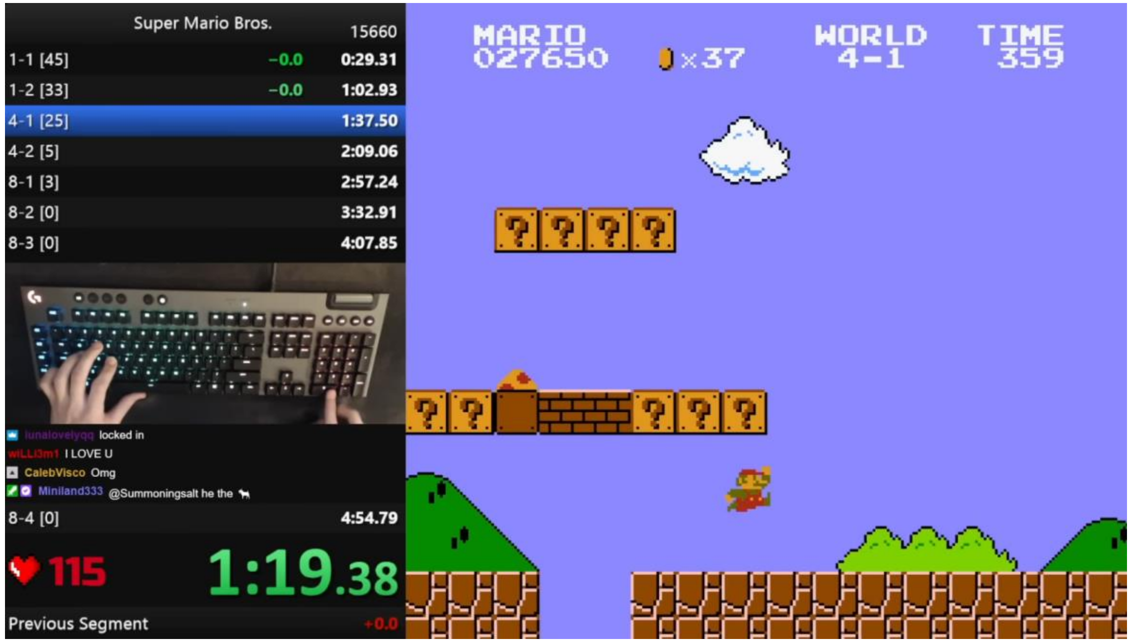
- The term Any% is borrowed from the video game speed running community.
- A video game speed run is an activity in which people attempt to complete the game in as little time as possible.
- Common types are 100% or Any%

Source: NASA

- Lean satellites tend to adopt ideas from lean manufacturing techniques.
- Lean manufacturing generally calls for process optimization and removing unneeded steps that slow down the delivery of value.
- Commonly CubeSats or other SmallSats

A Primer on Video Game Speed Running

Speedrun Clip of Super Mario Brothers – Credit: Sethbling, Source: Youtube



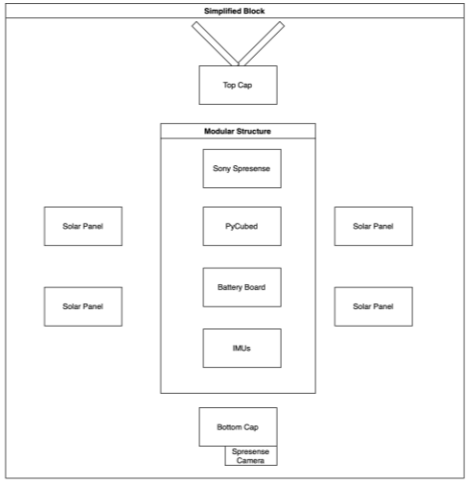
Speedrun Clip of Super Mario Brothers with Splits – Credit: Niftski, Source: Youtube

- Clip to the left is a speed run of a Super Mario Brothers level done by a YouTuber known as Sethbling

- Clip to the right is a speed run with "splits" of Super Mario Brothers done by a Youtuber known as Niftski

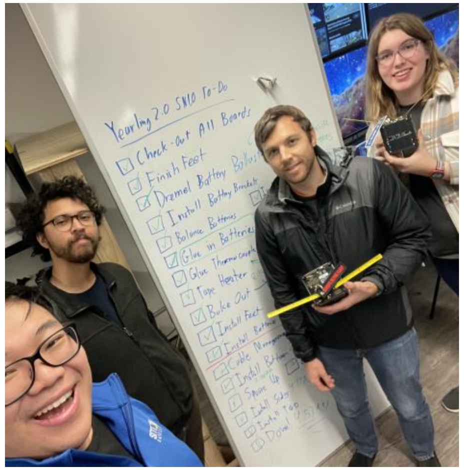
An Overview of the Any% Method

Goal Clarity



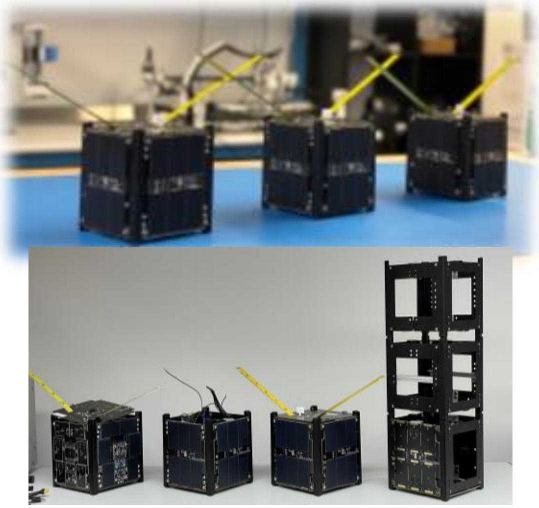
- Well defined and clearly understood goals
- Trying to limit to one or two essential objectives and no more

Benchmarking



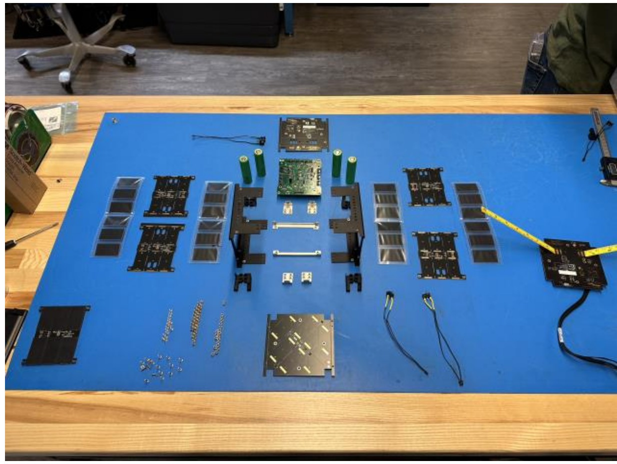
- Measure performance against the expectations of the community
- Use measured performance to inform needed improvements

Repetition & Refinement



- Improve through repetition.
- Practice key procedures in the same way one may practice an instrument

Route Optimization



- Explore alternative arrangements that avoid recurring issues
- Optimize by choosing the best route, rather than just refining one most traveled

Goal Clarity

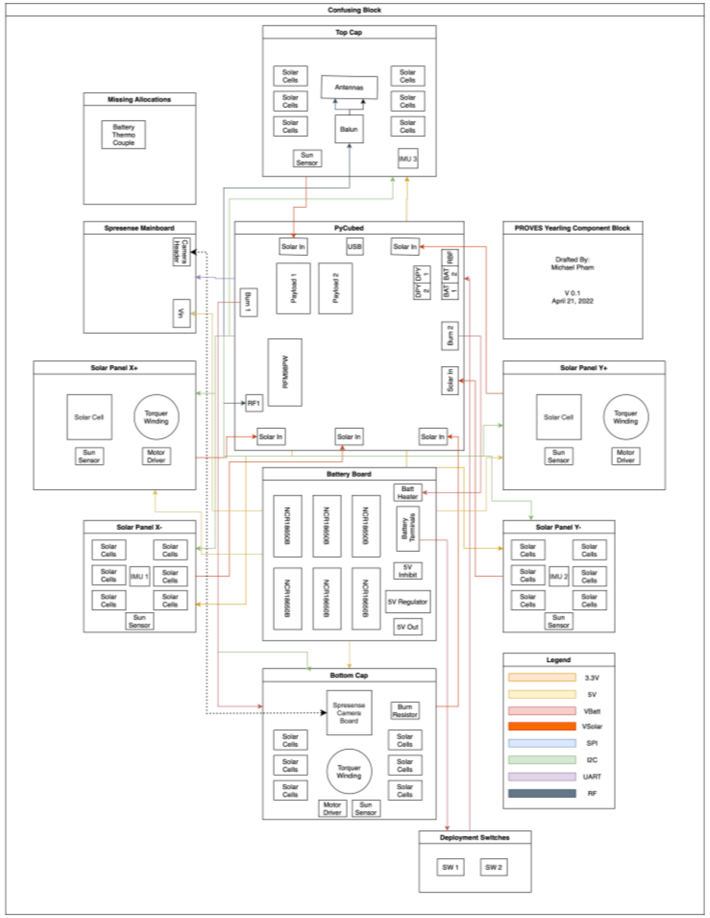
Key Points

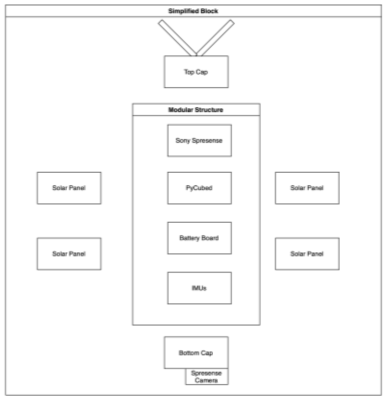
- **Clear Goals:** Every team member should know exactly what the overarching goal of the mission is, and how their personal objectives contribute to that goal.
- **Controlling Scope:** For lean missions, the goals and objectives should focus on the key value proposition of the mission. Additional goals should be disregarded until the key goal is met.

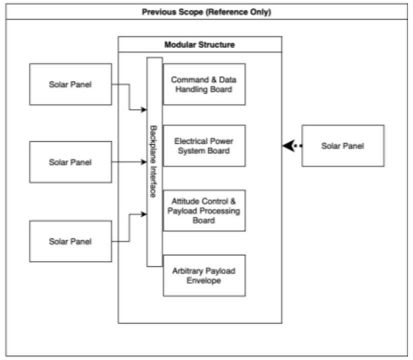
Key Lessons Learned

- A well understood and clearly defined goal keeps the team on track.
- Minimizing the scope of the goal(s) ensures that the project stays manageable.
- Goals should be changed if the need for them is no longer clear.

Clear Block Diagrams







Benchmarking

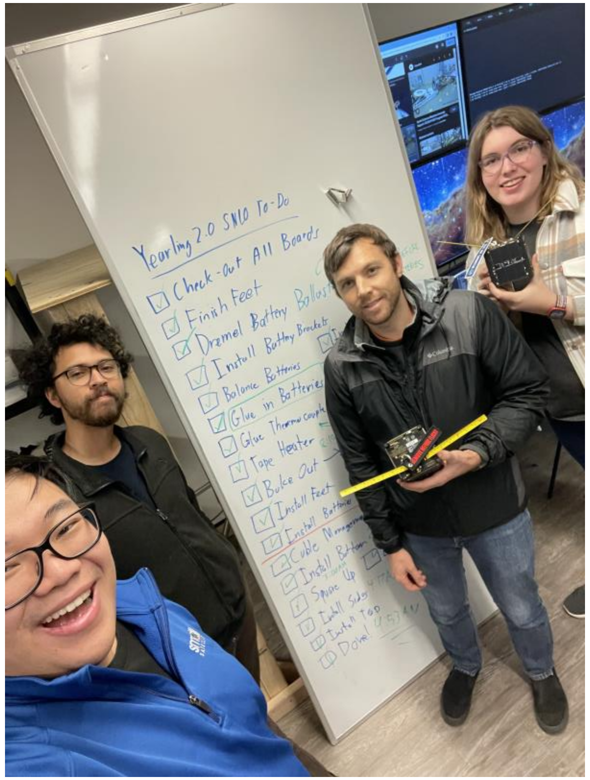
Key Points

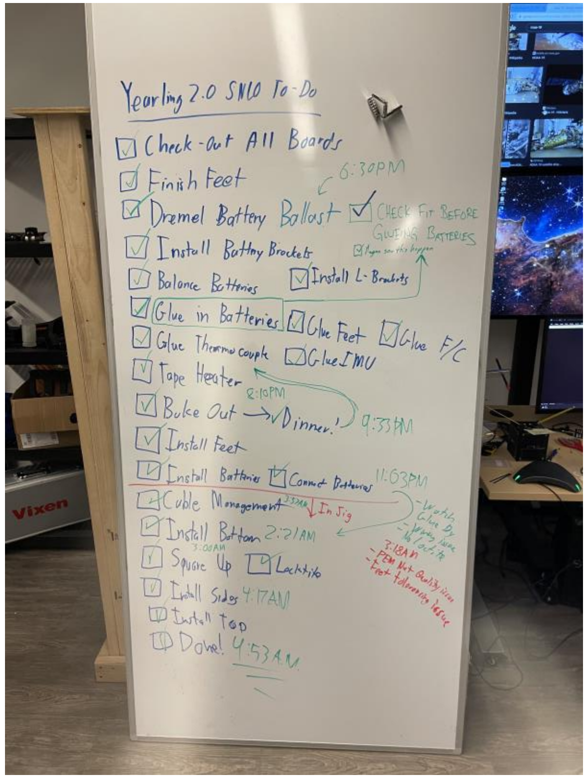
- **Use Data to Understand Your Process:** Just like how an athlete tracks the time it takes for them to run every mile of a marathon, engineers should track how long each step of their process takes.
- **Identify Bottlenecks:** Large improvements can come from focusing on improving the slowest steps rather than trying to generally be faster.

Key Lessons Learned

- Attempting to rush through the project holistically causes corner cutting and welcomes design flaws.
- Usually focusing on improving one or two critical operations (soldering, staking, testing, etc.) yields great results in optimization.

Time Trials





Repetition and Refinement

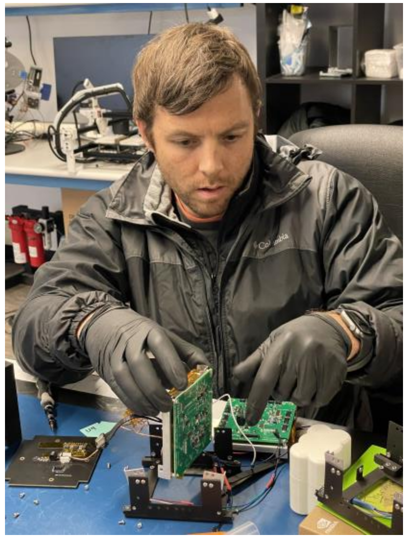
Key Points

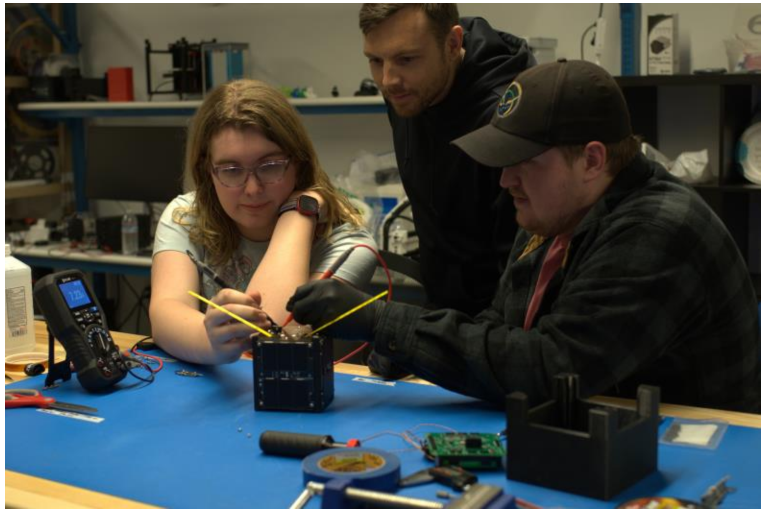
- **Building Skill:** Especially among new and academic programs building institutional knowledge is essential.
- **Treat it Like an Instrument:** Just as it takes multiple sessions in order to begin to build an intuition on how to place a musical instrument, it will also take multiple sessions to build an intuition for satellites.

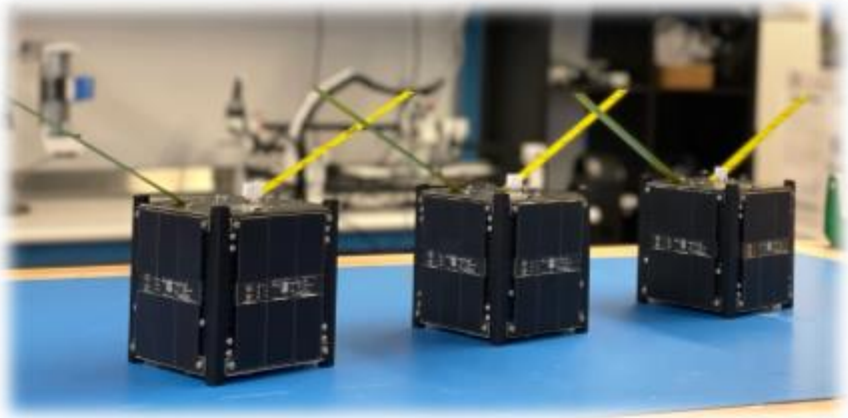
Key Lessons Learned

- Every time we do another integration of an engineering unit we get faster.
- As the engineers get experience building few mistakes are made and more design flaws are weeded out.
- Currently a PROVES Kit can be built in 4 hours.

Practice Makes Perfect







Route Optimization

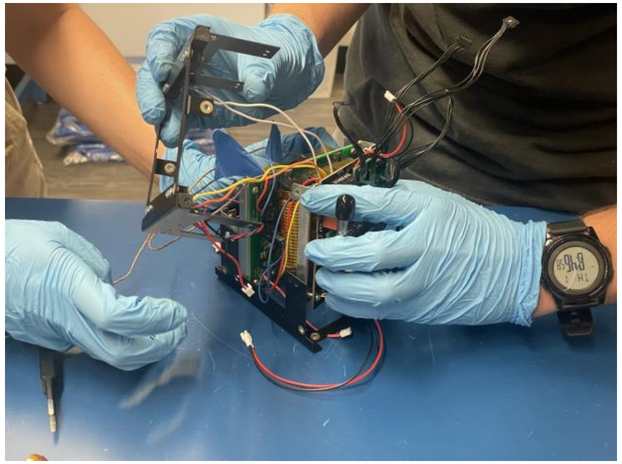
Key Points

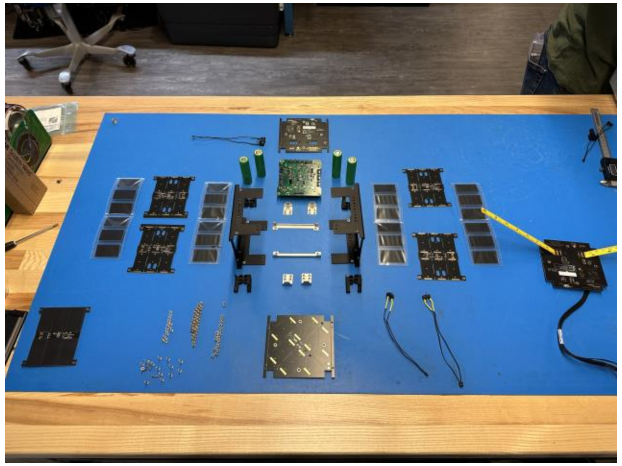
- **Discovering More Efficient Means:** Exploration must be done to find better ways to do things.
- **Engaging with the Community:** Learn from other architectures and what they do to succeed.
- **Avoiding the Critical Path:** Any operations that can stall the entire process should be avoided.
- **Parallelization:** Do as much in parallel as possible.

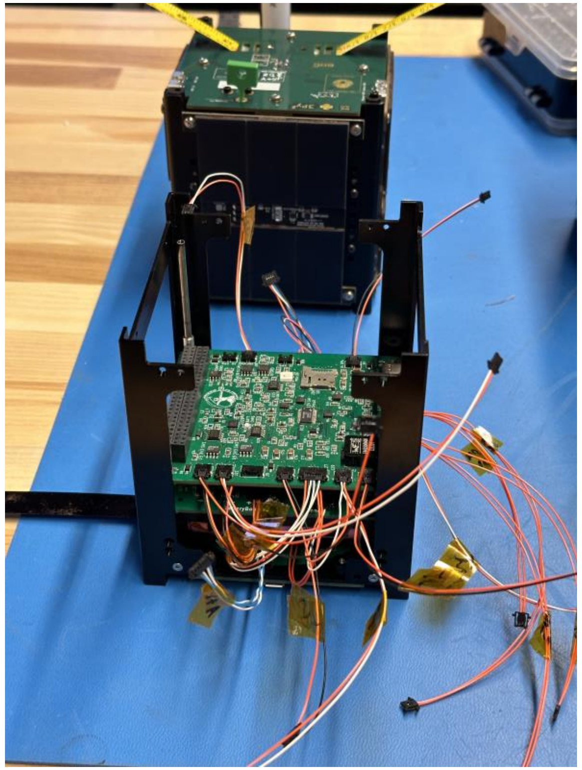
Key Lessons Learned

- Selecting a good path is essential to maintaining a high project velocity.
- Velocity is important to minimize mistakes and maintain schedule.
- If major operations can fit inside one working day and one working shift the number of potential mistakes decreases significantly.

Eliminating Complexity







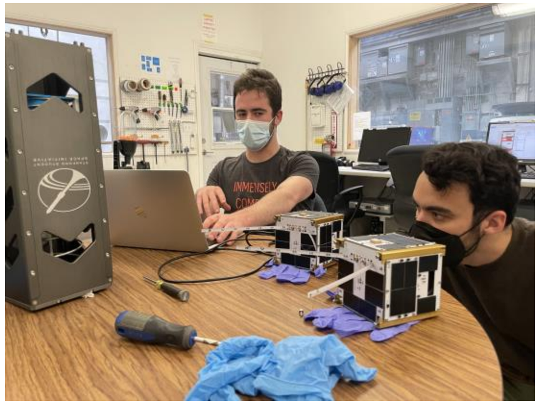
The Pleiades Five

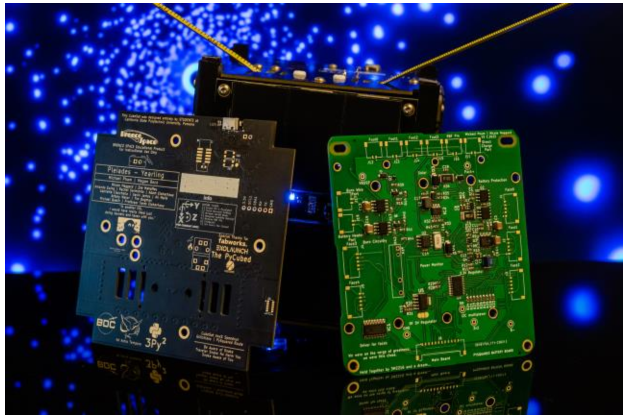
- Five unique universities joining Cal Poly Pomona in building and launching a cluster of six 1U CubeSats.
- Looking to study the dynamics of creating sustainable space programs at the participating universities.
- Implementing lessons learned from past university missions:
  - **Unified Architecture:** All universities flying a PROVES Kit at the core, with custom payloads as they wish.
  - **Joint Operations Plan:** Coordinated operations plan improves ground station availability and helps to streamline the licensing process.
  - **Compact Timeline:** Compacting the student experience to 1 year. Aligns with other popular student engineering experiences and minimizes the chance of program disruption and delay.

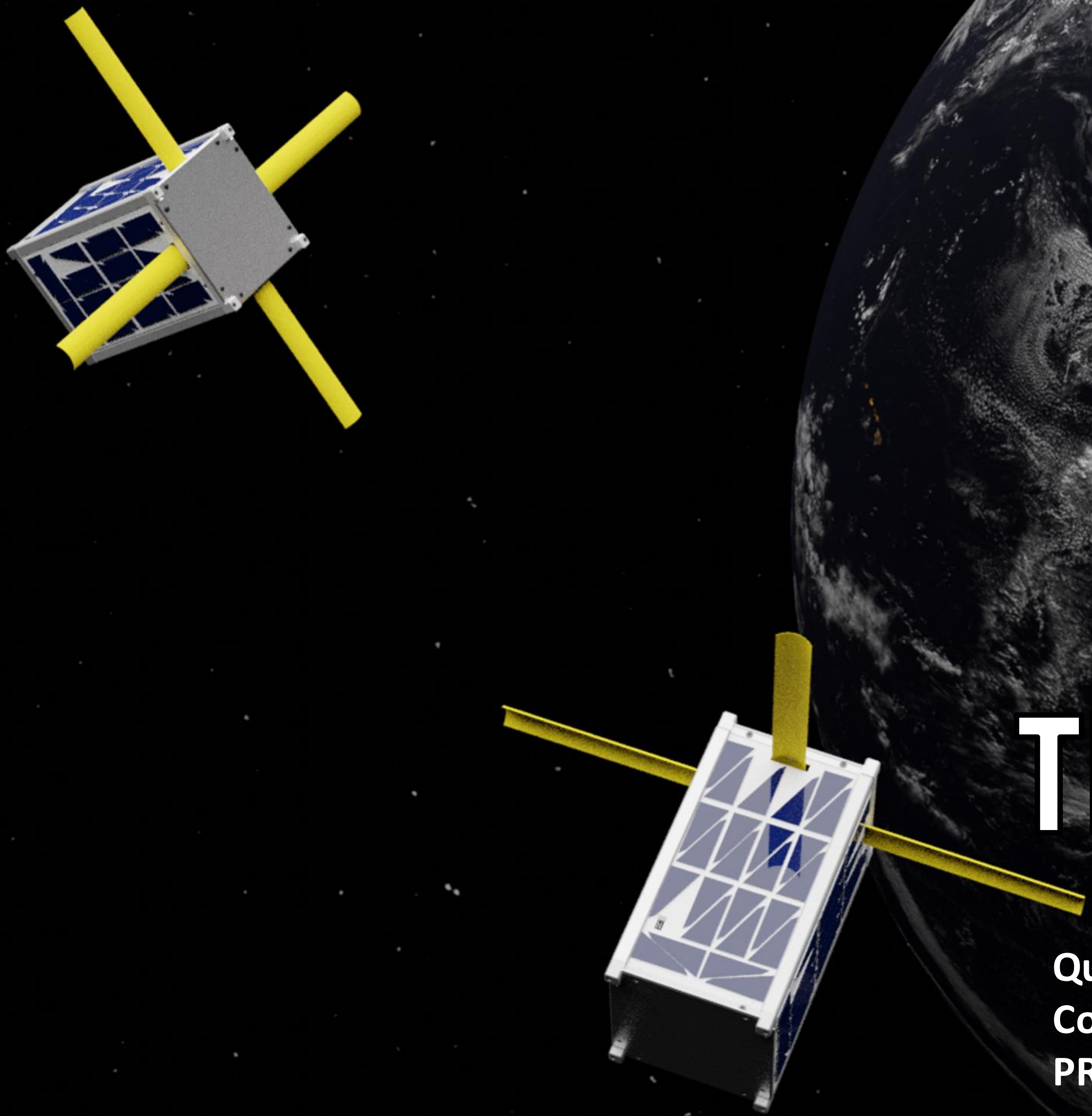
Recommendations for the CubeSat Community

Potential Solutions

- Push an understanding of Academic CubeSats as primarily or purely educational tools.
- Discuss cost more openly and drive for CubeSats to become more accessible through significantly lower cost.
- Reduce the timeline of academic CubeSats to align them with other successful student programs.
- Promote and participate in collaborative channels and share data and designs openly.
  - **Support open CubeSat architectures!**
    - Like the 1U PROVES Kit







Thank You!

Questions?

Contact: mlpham@cpp.edu

PROVES Kit Open Source: github.com/proveskit