Lessons Learned from 4 University CubeSats on 4 Back-to-Back SpaceX Transporter Launches

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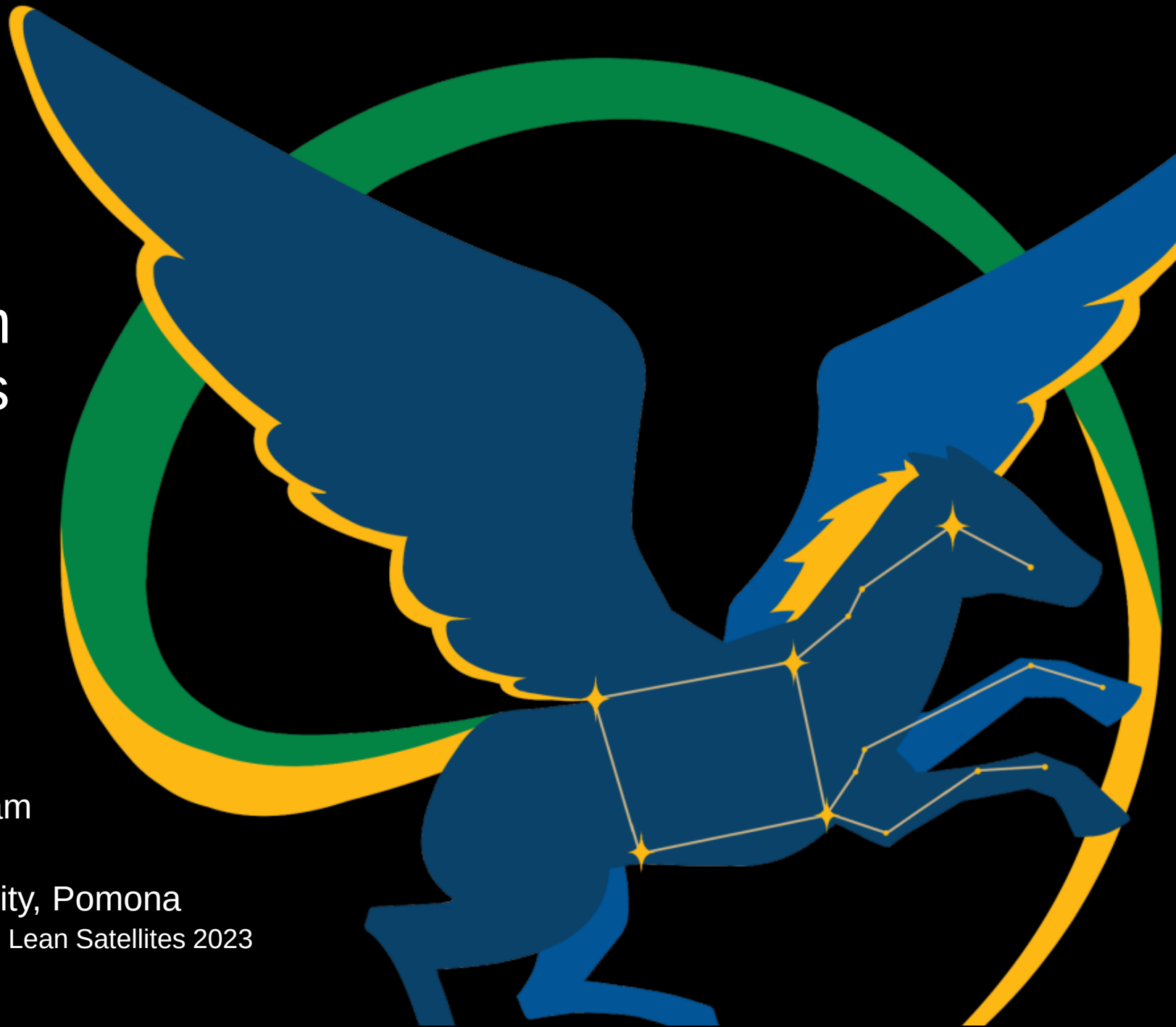
California State Polytechnic University, Pomona

For Public Release at the International Workshop on Lean Satellites 2023

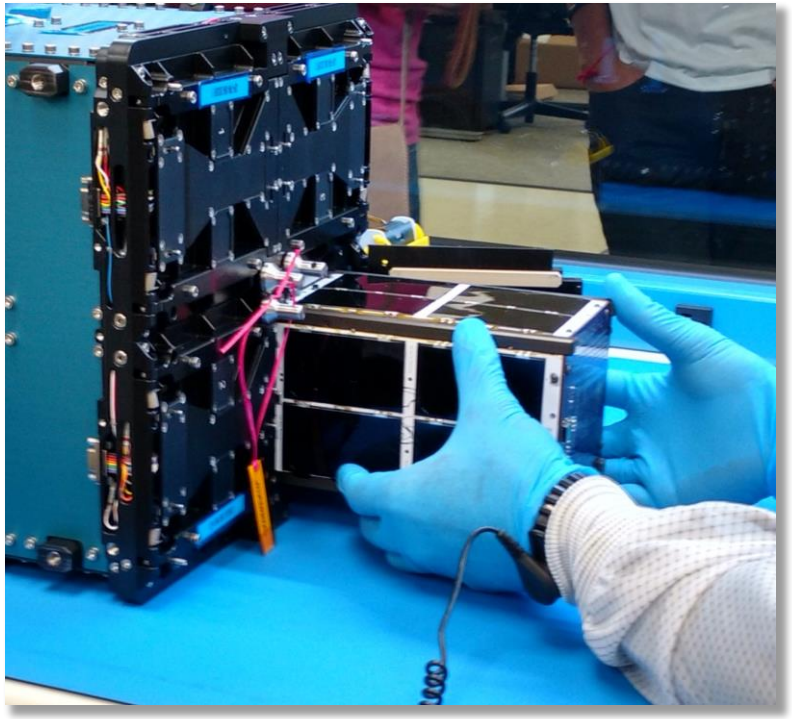
December 4, 2023



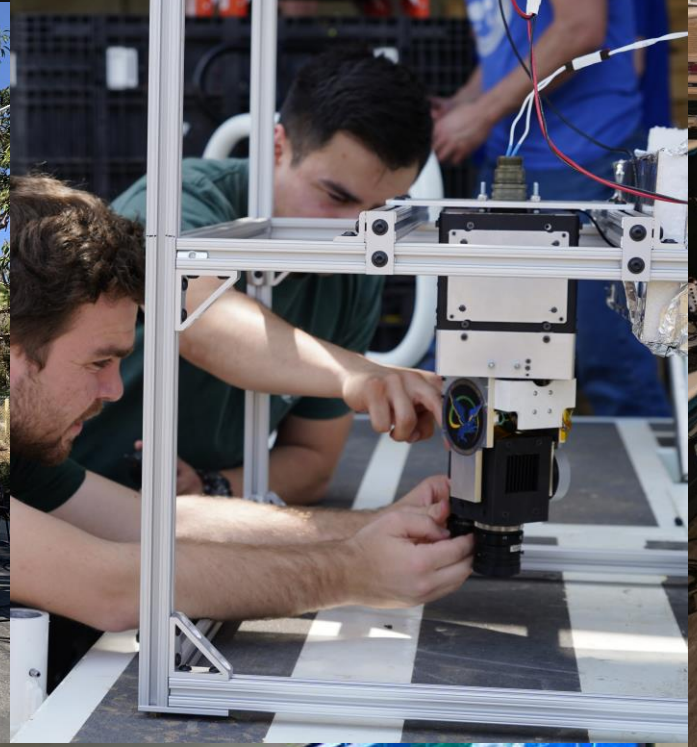
About Bronco Space

- 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.

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).




LAUNCHER

BroncoSat-1 Mission Results

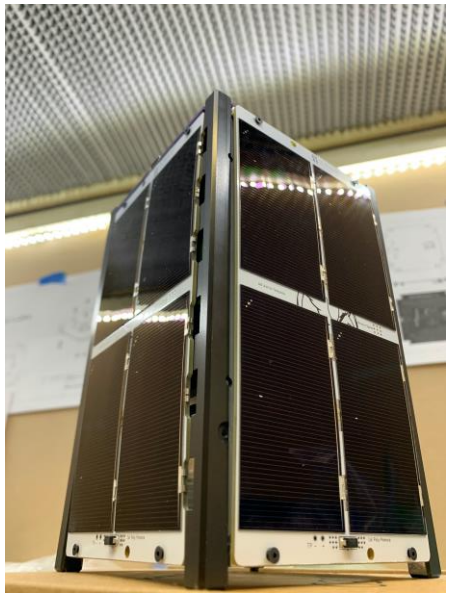
Mission Metrics

- **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

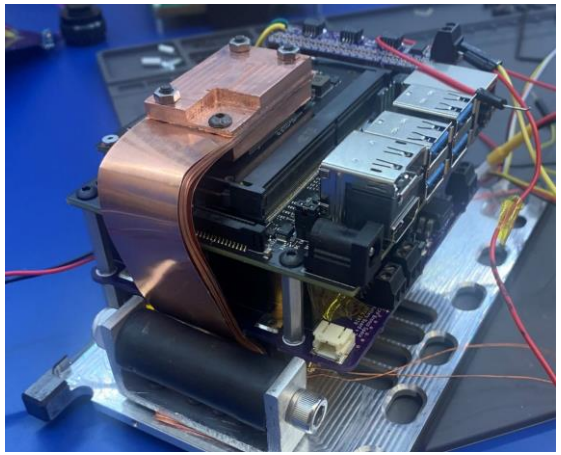
- Do not trust performance claims from COTS vendors without independent validation.
- Closed source and non-transparent designs are not conducive to an academic project.
- It is possible to deliver a CubeSat with very little in person involvement if properly managed.

BroncoSat-1



Key BroncoSat-1 Design Elements

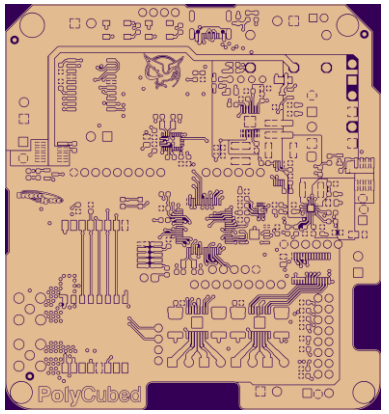
Test, Fix, Retest

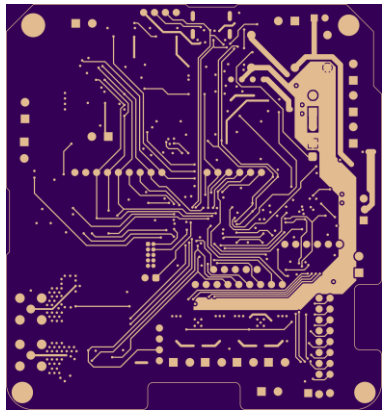


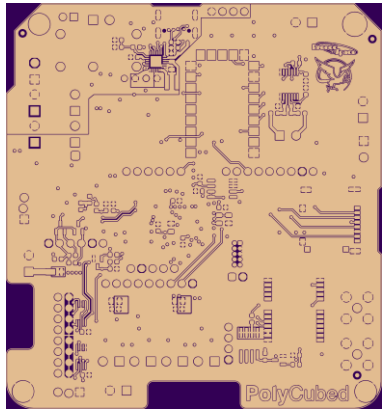
Design Optimizations

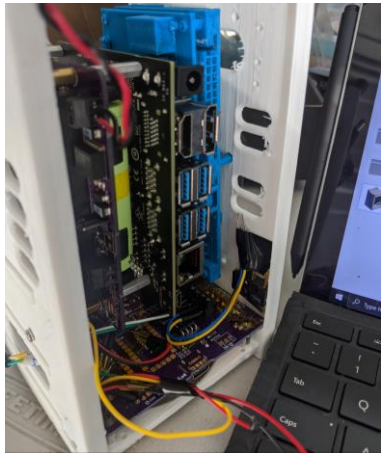
- Expendable prototypes allowed for very quick design validation and flexibility in student training.
- PolyCubed modification of the PyCubed architecture was our first engagement with open source CubeSat hardware.

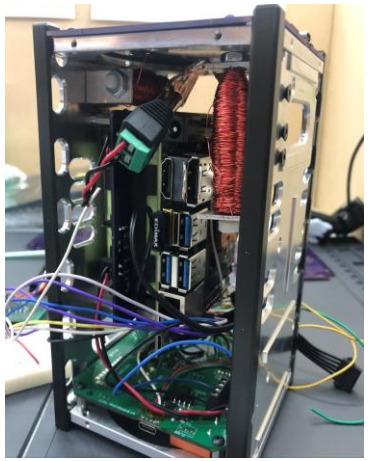
Intensive Iterations











Pleiades – Yearling 1 Mission Results

Mission Metrics

- **Mission Objective:** Flight Validation of PROVES Kit
- **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)

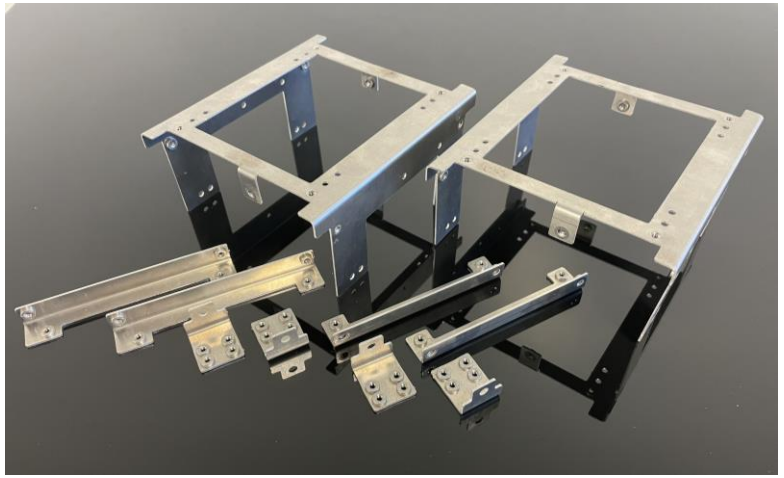
Key Lessons Learned

- 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

Key Pleiades – Yearling 1 Design Elements

Sheet Metal Savings



Design Optimizations

- Introduction of sheet metal structure, saving 80% in cost and 50% in lead time over CNC design.
- Repurposed “maker” hardware for spaceflight applications to reduce design overhead, cost, and lead time.

Adafruit Breakout Boards in Space

Pleiades – Yearling 2 Mission Results

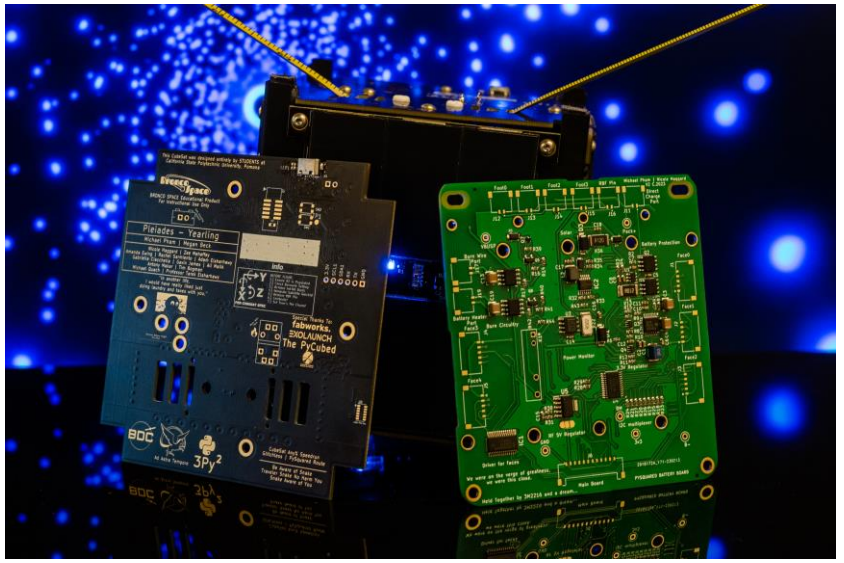
Mission Metrics

- **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

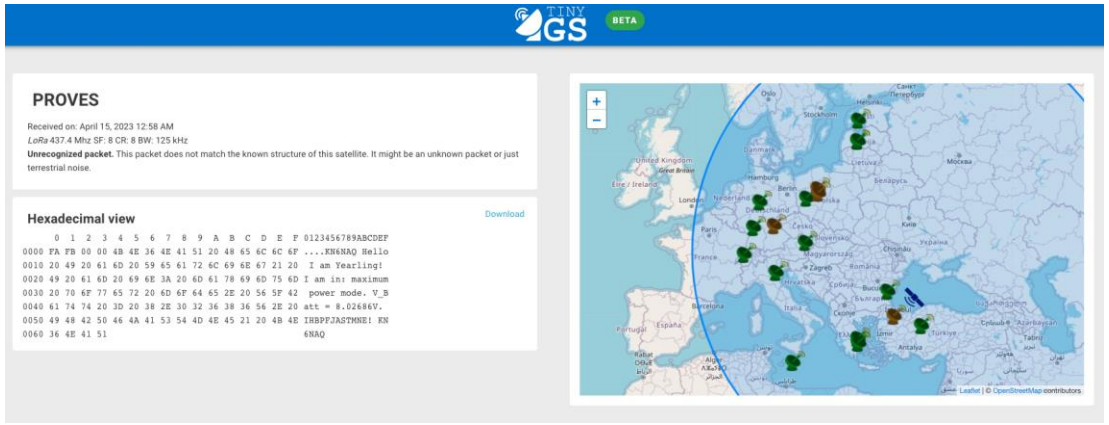
- ”Think slow, act fast” design philosophy works very well for rapid iteration of designs.
- Parallel workflows are essential to quick design, build, test, fix loops.
- Responsive and fast early mission ops is extremely important. Utilize global community networks whenever possible.

Yearling - 2



Key Pleiades – Yearling 2 Design Elements

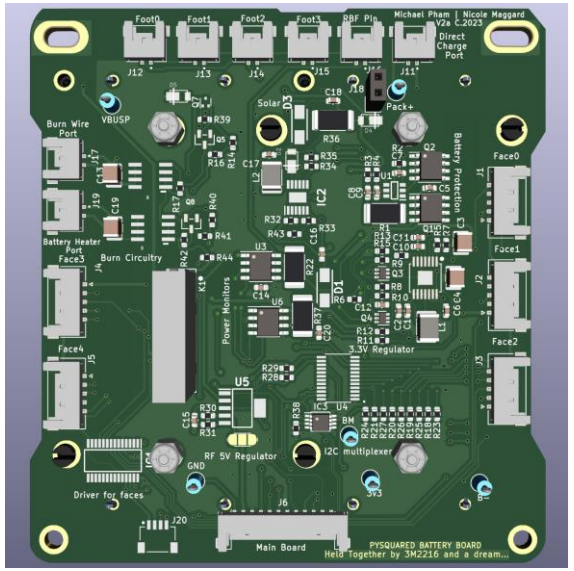
Making Changes Faster and Better

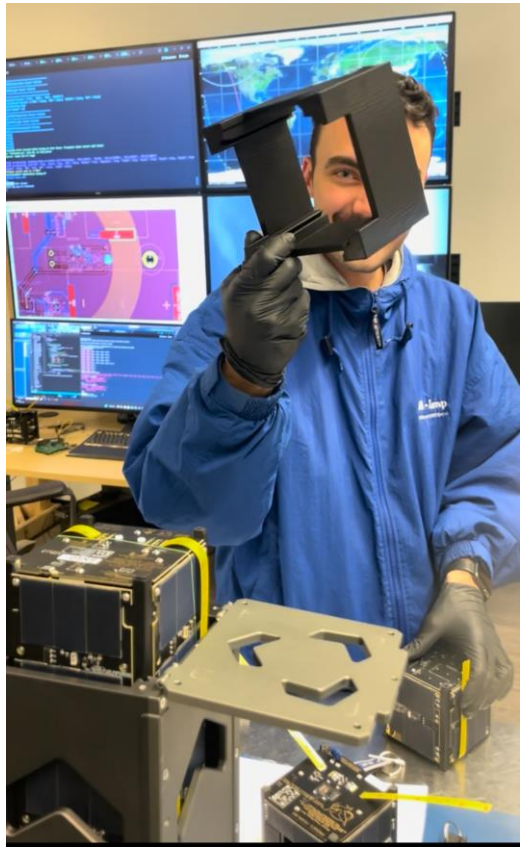


Design Optimizations

- Significant overhaul of internal PCBs to eliminate “fly wires” and reduce the points of potential mishap during integration.
- Two week design, build, test, redesign cycle
- Fully invested in TinyGS ground station network to autonomously collect data in an open-source manner.

Improving Usability





Pleiades – Squared Mission Results

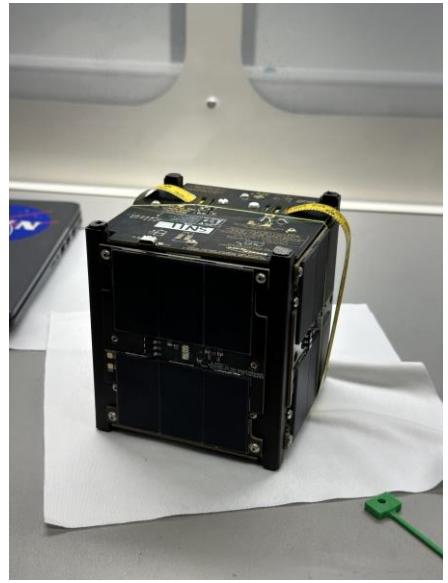
Mission Metrics

- **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



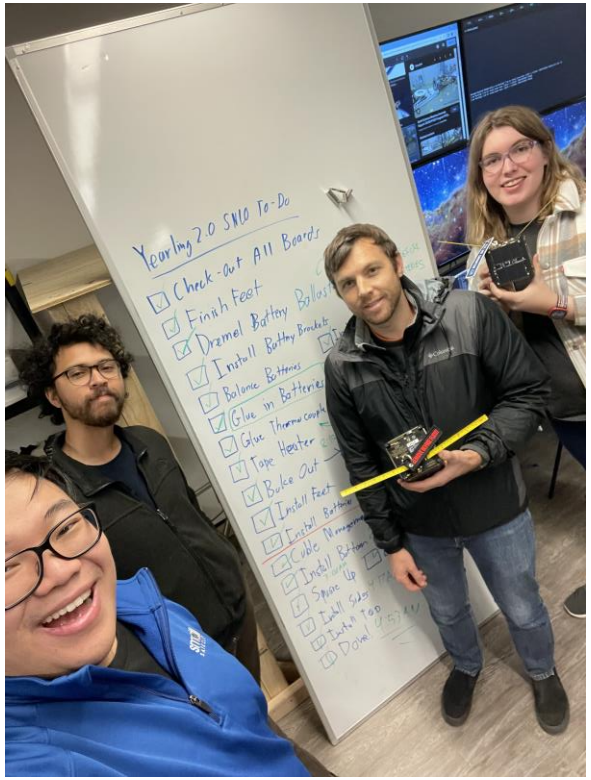
Key Pleiades – Squared Design Elements

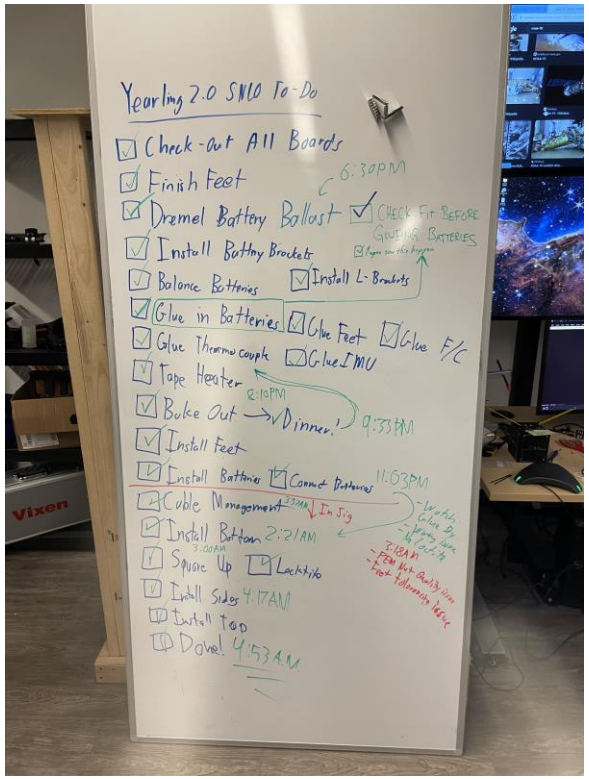
Peak Performance

Design Optimizations

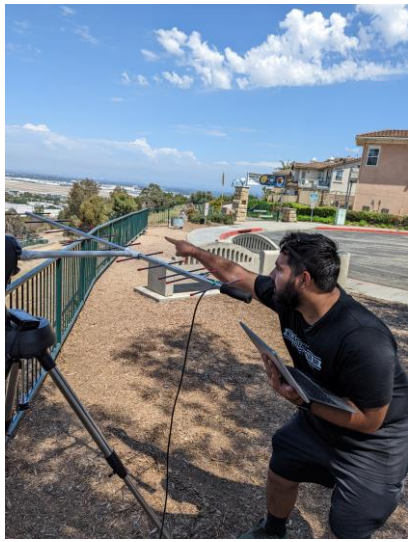
- An experienced and motivated team was the single biggest determining factor towards the success of the Pleiades – Squared mission.
- Good training through successive satellite integrations and clear understanding of what needed to be done were essential.

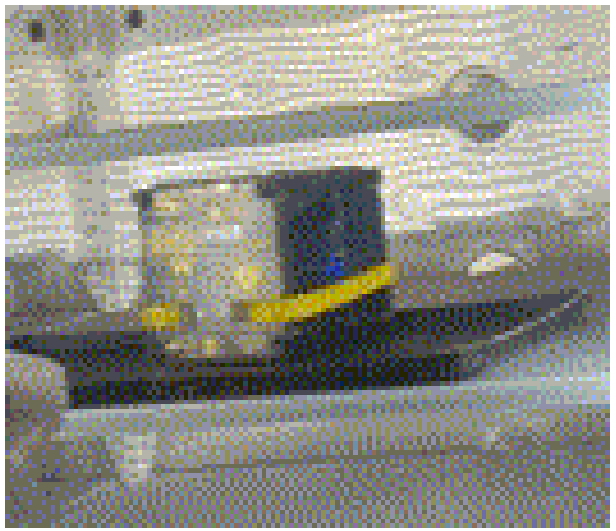
From Building Satellite Intuition

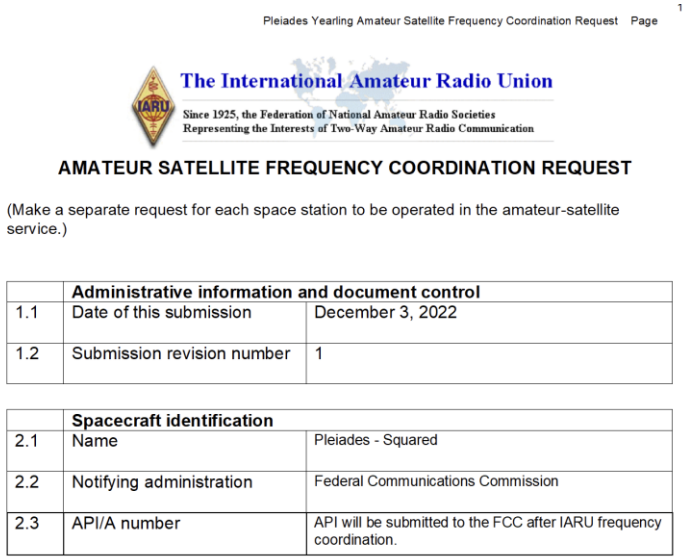




Reinforcing Common Lessons







Pleiades Yearling Amateur Satellite Frequency Coordination Request Page 1

The International Amateur Radio Union

Since 1925, the Federation of National Amateur Radio Societies
Representing the Interests of Two-Way Amateur Radio Communication

AMATEUR SATELLITE FREQUENCY COORDINATION REQUEST

(Make a separate request for each space station to be operated in the amateur-satellite service.)

	Administrative information and document control	
1.1	Date of this submission	December 3, 2022
1.2	Submission revision number	1

	Spacecraft identification	
2.1	Name	Pleiades - Squared
2.2	Notifying administration	Federal Communications Commission
2.3	API/A number	API will be submitted to the FCC after IARU frequency coordination.

California State Polytechnic University, Pomona

0746-EX-CN-2020

Status: Pending

N/A
2020-09-01

Documents and Communications: [refresh]

Description	Category	Date
Space Antenna Tx Pattern Duplex	Images	2020-09-01
Space Antenna Rx Pattern Duplex	Images	2020-09-01
Space Antenna Tx Pattern Simplex	Images	2020-09-01
Applicant Type	Text Documents	2020-09-01
Technical Description	Text Documents	2020-09-01
Stop Buzzer Designation	Text Documents	2020-09-01
Orbital Debris Assessment Report	Text Documents	2020-09-01
NOAA License Waiver	Text Documents	2020-09-02
Fee Exemption Request	Text Documents	2020-09-02
ITU Cost Recovery Letter	Text Documents	2020-09-02
Operating Agency Symbol Request	Text Documents	2020-09-02

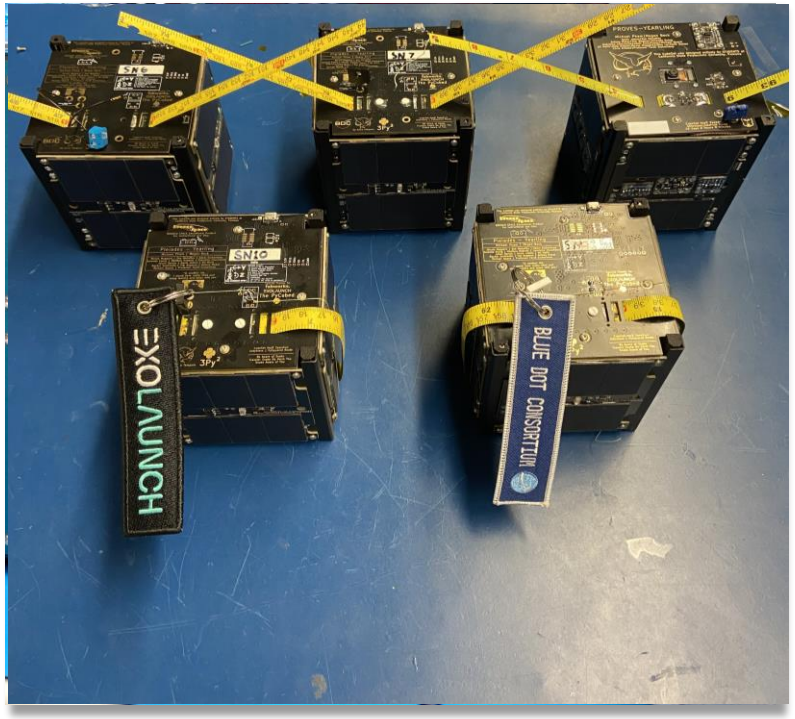
Application Form:

FCC FORM 442 - FEDERAL COMMUNICATIONS COMMISSION
APPLICATION FOR NEW OR MODIFIED RADIO STATION UNDER PART 5 OF FCC RULES - EXPERIMENTAL RADIO SERVICE (OTH THAN BROADCAST)

- **“Test Early, Test Often”**
  - Frequent testing allowed us to weed out problematic components and operational scenarios.
  - Don’t only test flight hardware, also extensively test engineering units and expendable test units to better understand part variance and failure modes.

- **“Start Licensing Early!”**
  - Without starting IARU coordination very far in advance we would not have been able to fly any of our satellites.
  - If flying on a host vehicle, make sure the host is properly licensed as well! Yearling-1 almost was rejected for flight because of this issue.

The PROVES Kit

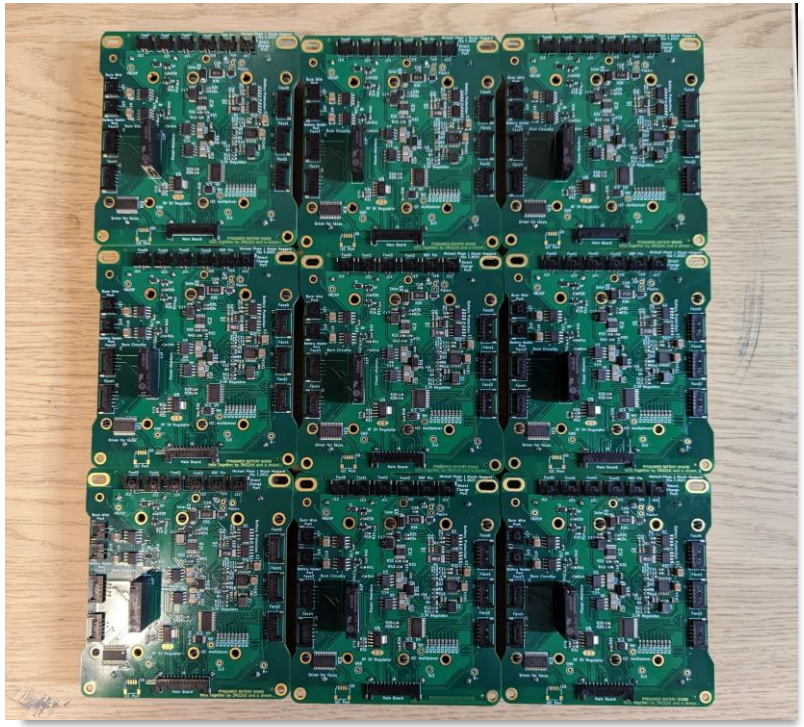


- 16 PROVES Serial Numbers assigned since the beginning of 2023
- Another 5 builds are in progress at various partner organizations.
- Currently there are 8 university users of the PROVES Kit and 2 high school users.

open source hardware

Design for Mass Manufacturing

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



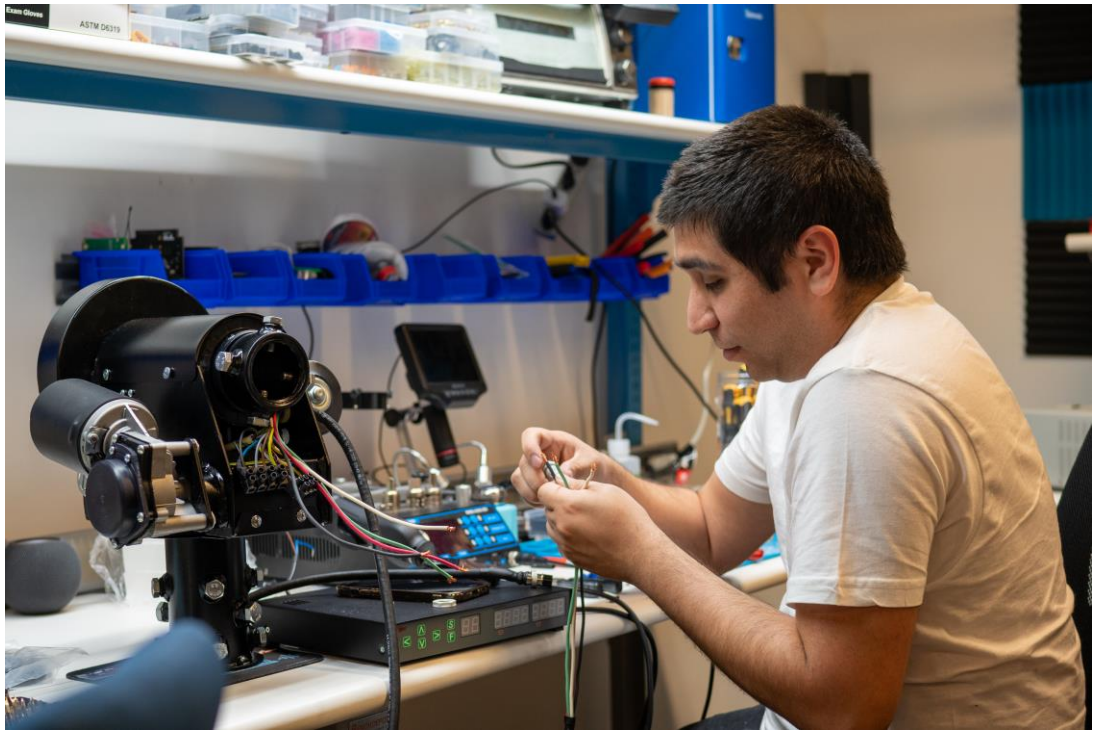
- Single sided PCBs that could be quickly SMT assembled and with parts already at the board house.
- Completed sub-assemblies can be binned for quality.

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

What Should an Academic CubeSat Be?

Current Issues

- Perceived need for a high performing mission causes universities to over scope.
- Costs are often poorly understood, and way underestimated.
- Revolving door turnover in academic projects torpedoes productivity on multigenerational programs.
- Siloed development and a lack of community knowledge lead to many mistakes being made multiple times.



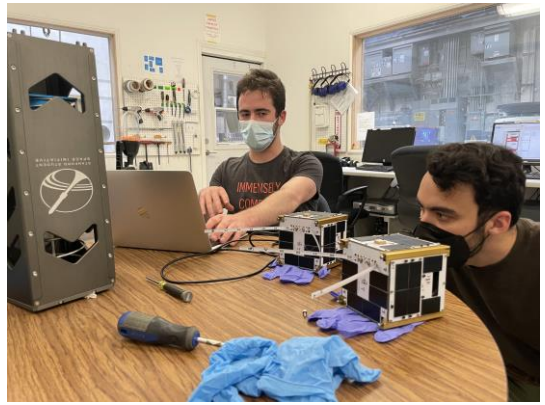
The Pleiades Five

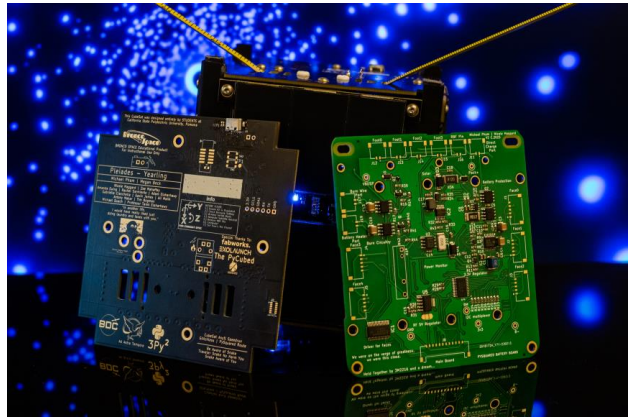
- Five unique universities joining Cal Poly Pomona in building and launching a cluster of six 1U CubeSats.
- Looking to study the dynamics of creating sustainable space programs at the participating universities.
- Implementing lessons learned from past university missions:
  - **Unified Architecture:** 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.

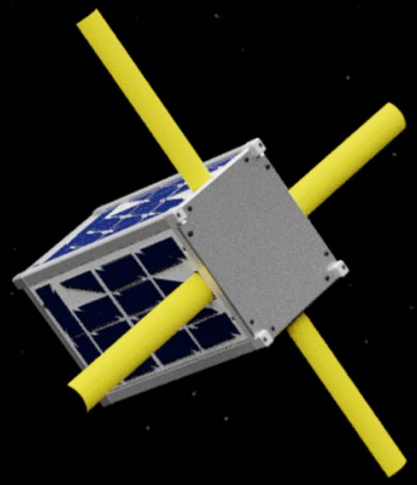
Recommendations for the CubeSat Community

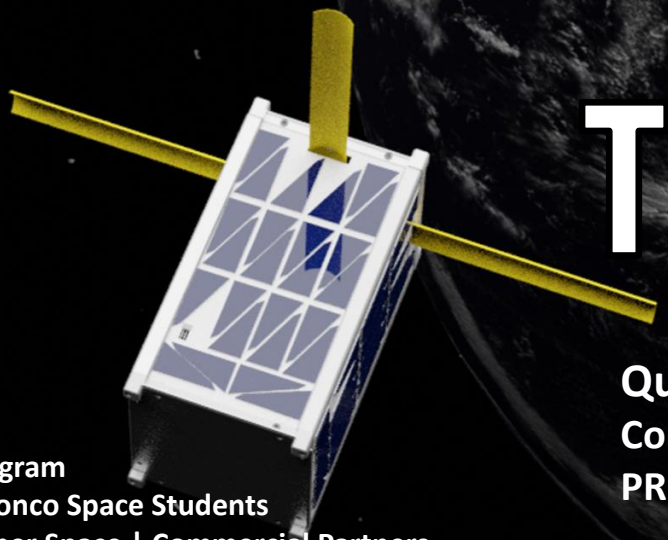
Potential Solutions

- 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!

Acknowledgments:

- Tarek Elsharhawy | Bronco Space Primary Faculty Advisor
- Mike Beckage | Philanthropic Funding for the PROVES Program
- Cal Poly Pomona's College of Engineering | Support for Bronco Space Students
- Quanta Laboratories, Momentus Space, Exolaunch, Launcher Space | Commercial Partners

Questions?
Contact: mlpham@cpp.edu

PROVES Kit Open Source: github.com/proveskit