Flight Results Including the ThinSat-2 Constellation, TROOP Payload Host, and Miniaturized GPS Integrated into the EyeStar-S3

CubeSat Developers Workshop 2021

Matthew B. Orvis, mattorvis@nearspacelaunch.com
Jeff F. Dailey
Hank D. Voss
Jonathan N. Fritsch

NearSpace Launch, Inc®
Technology. Service. Education

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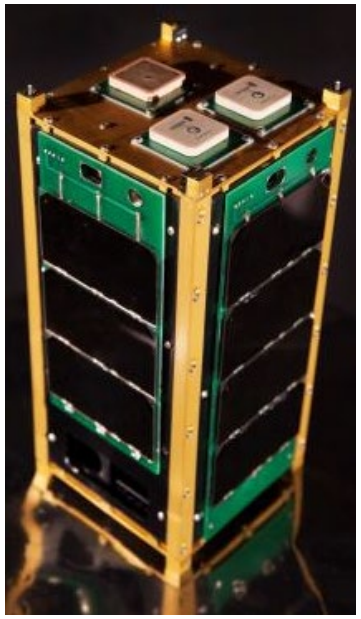
https://qz.com/1961141/spacexs-record-setting-satellite-launch-boosts-space-tug-biz/

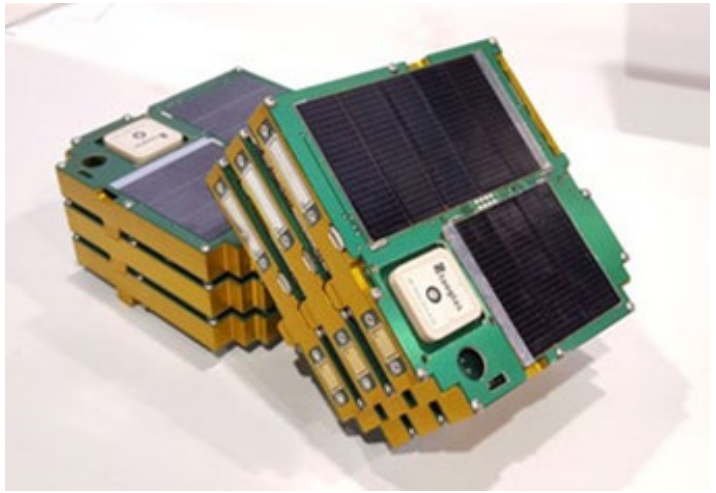
NearSpace Launch (NSL)

- NSL 100% mission success (1U-6U CubeSats & Subsystems)
- Heritage
  - 600+ NSL systems launched total (200+ in last year)
  - 300+ NSL systems manifested in coming years
  - 130+ Globalstar connected radios launched
- Products
  - FastBus CubeSat: 1U – 12U
  - ThinSat: 1/7U – 12U
  - EyeStar Comms: EyeStar-S3, EyeStar-Tag, EyeStar-D2
  - Black Box: Standard, Patch, PC104
  - TROOP: Train Rapid On Orbit Payload (Host)
- Customers
  - DOD, Air Force, Space Force, DARPA, NASA, Boeing, Nanoracks, Spaceflight, Inc., Rocket Lab, NovaWurks, MIT, plus many other industry and educational groups
- Partners
  - Globalstar Inc., Twiggs Space Labs, Sterk Solutions, Pumpkin, Spaceflight, Inc.
- NearSpace Education (NSE) – STEM Division spinoff (CubeSats and ThinSats)
- Won
  - Phase II SBIR with Space Force – ThinSat – RapSat
  - Phase I SBIR NASA Space Weather – ThinSat – SWAP-E
  - Hyper Space Challenge



2U FastBus CubeSat

Black Box - Standard

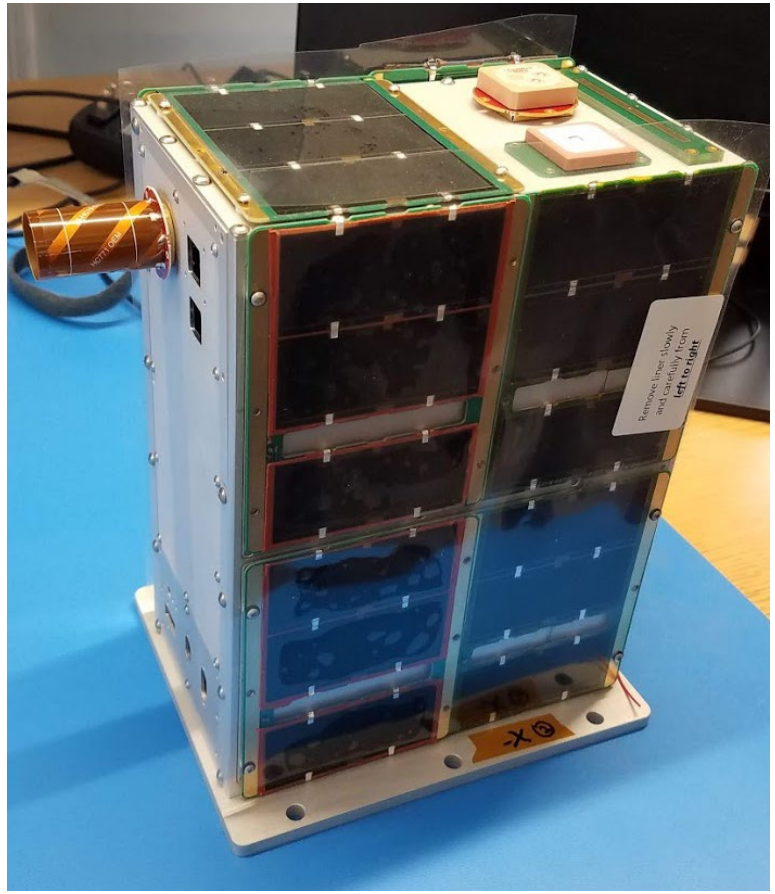


Set of 1/7U ThinSats

Year in Review

- 2021 (so far)
  - TagSat-1 (TROOP-1) – SFI/NSL – 1U FastBus/TROOP System
  - SHERPA-FX1 Tag – Spaceflight, Inc. – Black Box – Standard
  - ThinSat-2 – VCSFA/TSL/NSL – ThinSat Constellation
  - M2A – UNSW Canberra – S3
  - M2B – UNSW Canberra – S3
- 2021 (upcoming)
  - BeaverCube – MIT – Black Box – Patch
  - BroncoSat-1 – Cal Poly Pomona – Black Box – Patch
  - TROOP-2 – SF/NSL – 4U FastBus/TROOP System
  - BSS-1 – Benchmark Space Systems/NSL – 3U FastBus
  - Orbital-1 – Naval Postgraduate School – 2U FastBus
  - ARICA – Aoyama Gakuin University – S3
  - Maxwell – University of Colorado – S3
  - TROOP-3 – SF/NSL – 4U FastBus/TROOP System

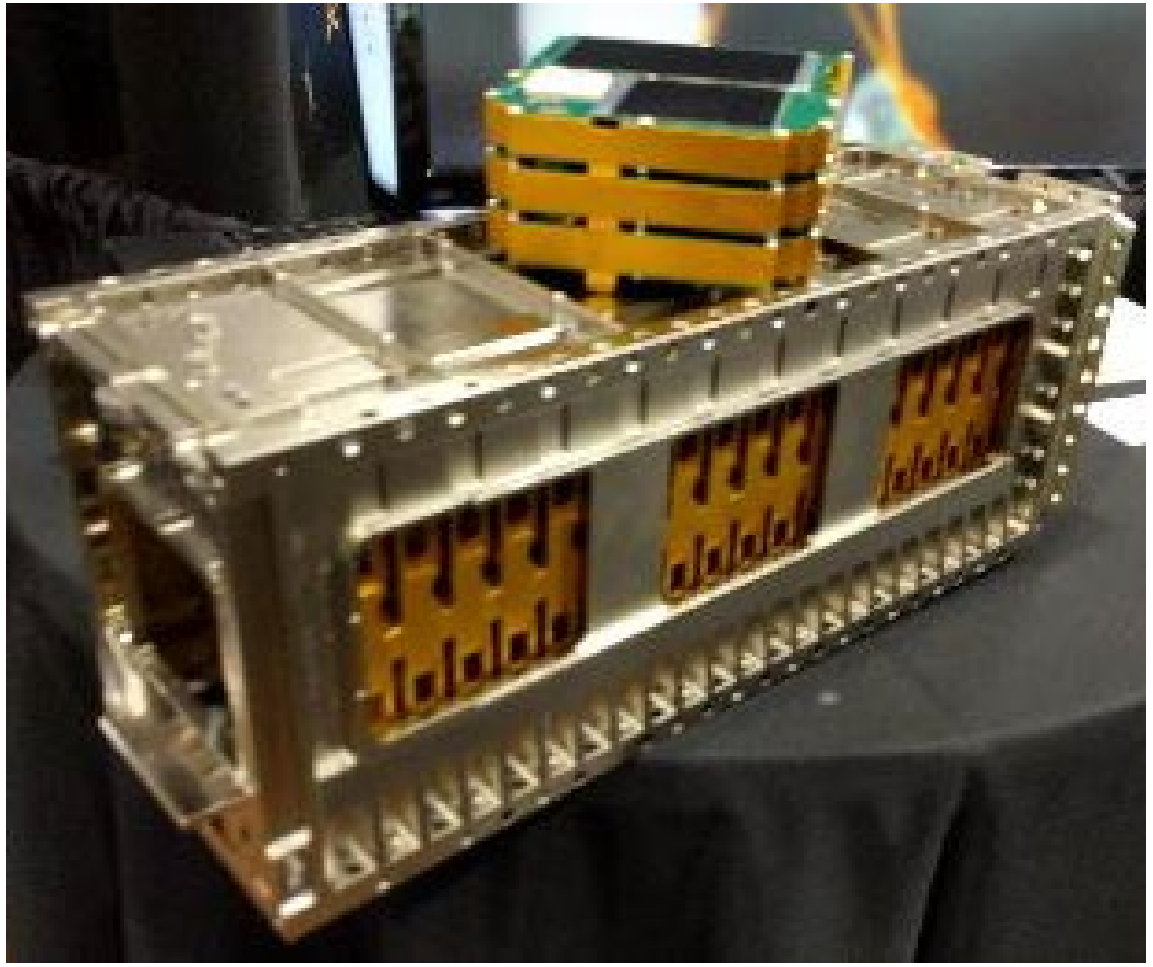
ThinSat-2 Stack



TagSat-2 (TROOP-2)

ThinSat-2 – Overview

- ThinSats are 1/7U CubeSats (up to 12U), designed to deploy in constellation and operate independently
- 30 ThinSats launched from NG-15 on 2/20/2021
  - 180 x 260 km orbit, 51.6° inclination
  - Designed to work at all altitudes
  - Inaugural launch was 60 ThinSats on NG-11 on 4/17/2019
- Built in partnership with VCSFA and TSL
  - Involvement from over 45 schools around the nation
- STEM project handled by educational division, NearSpace Education (NSE)
- 2x 3U Stacks, with 42 slots, filled by 30 ThinSats
  - Several 2T's, & a 6T
- Can mix 1T to 6T, and CubeSats, with different length strings
  - Connected in sets of 8, 6, 5, and 2, along with single flyers



ThinSats stowed in PSC deployer

Why ThinSats?

1. **Automated Assembly** using two exterior parallel PC Board composite & structural assembly, shielding for radiation and EMI reduction (pancake assembly), Globalstar/NSL EyeStar product fits with 24/7 real-time monitoring for ordered database.
2. **Advanced Manufacture** and robotic mass assembly with modular ThinSat frames and 3D printing.
3. **Easy Testing** and debugging of ThinSat since it is comparable to a Flat-Sat. Easy workflow with multiple subsystems.

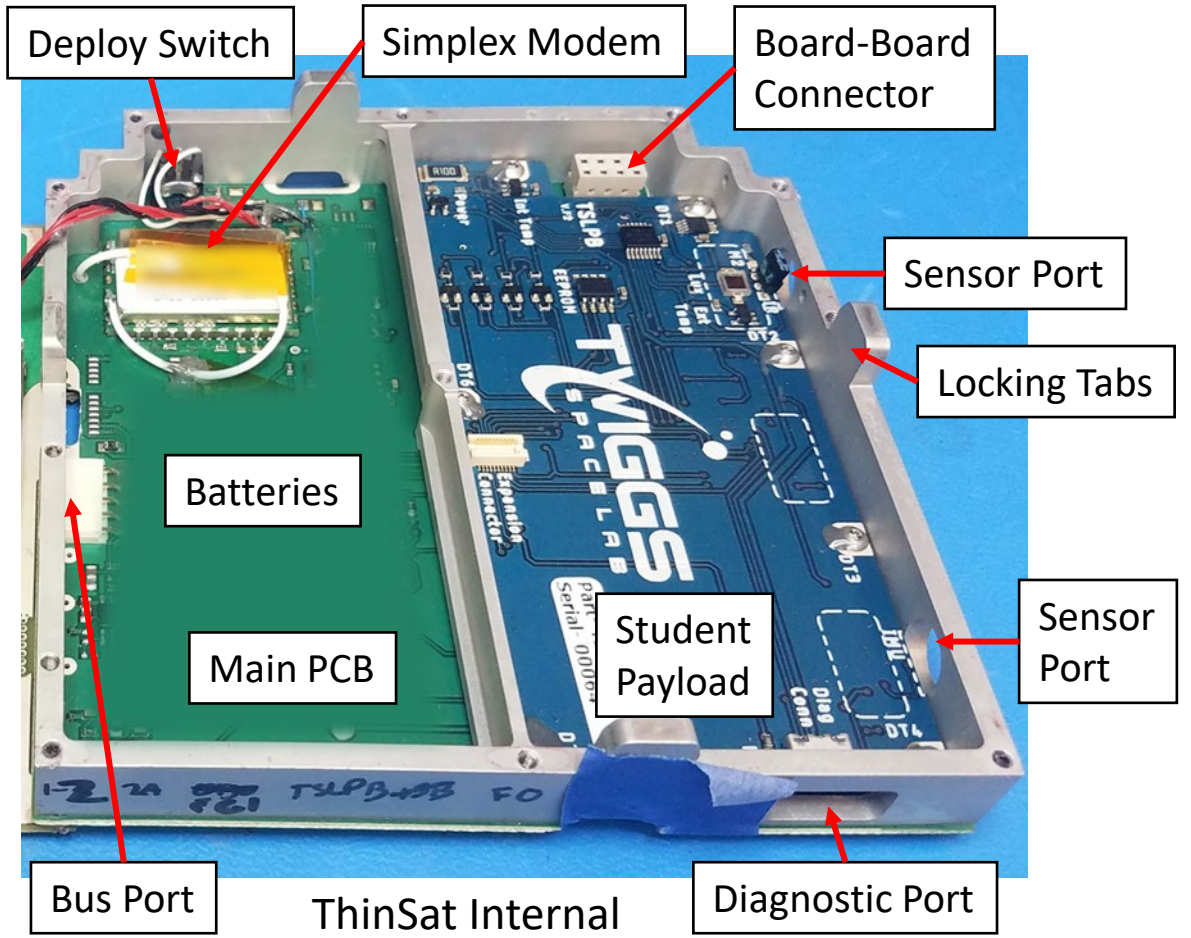
Costing

1. **Significantly lower cost** by a factor of 10 for constellations to **manufacture** compared to using many smaller PC boards with connectors. One main PCB with few connectors.
2. **Reduce Cost** with 1/6U size satellite cost and **reduce launch mass** by 1/6 ~ 1/10 cost of 1U
3. **Delivery in 6 months** from start of production lower labor time and other timeline costing

Set of 1/7U ThinSats

ThinSat-2 – Overview – Single ThinSat

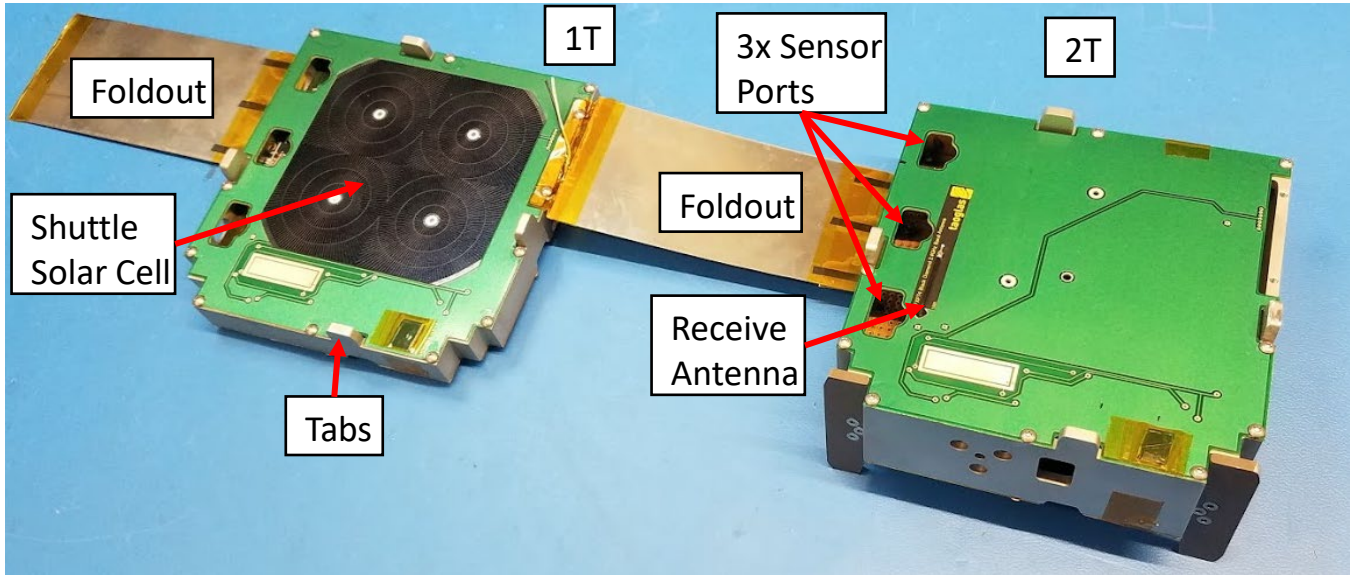
- Flat for ease of robotics, assembly, testing, solar area
- ½ of volume dedicated to Payload
  - 5x view ports, data + power
- ½ of volume dedicated to Bus
  - EPS, batteries, FP, Comms (TX, RX, GPS), inhibits, sensors, solar, etc.
- 2T Motherships included
  - 3 axis ADCS
  - Larger GPS
  - Extra Sensors
- Solar arrays included to extend life, not for battery recharging (2 day mission)
- EyeStar-S3 Globalstar connected transmitter
  - 24/7 global coverage, live streaming data
  - Data made available live on the online Space Data Dashboard



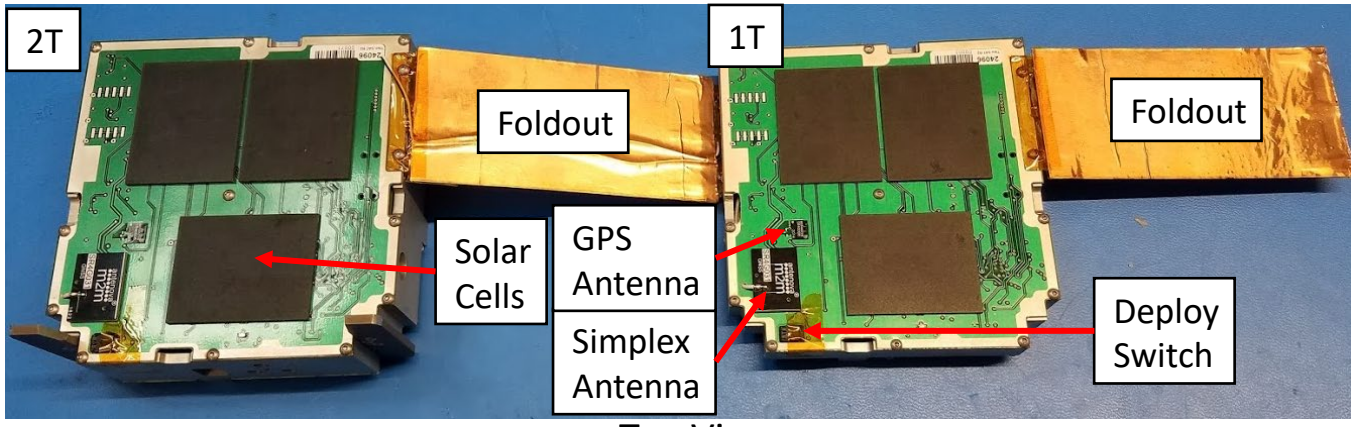
ThinSat Internal

ThinSat-2 – Overview – Assembly

- Foldouts between ThinSats
  - ThinSat deployment mechanism (NiTi hinge)
  - Transfer data/power
  - Extra Solar Area
  - Boom deployment
- Connected in strings (1 – 8 Sats)
  - Shared location/data/power
  - Project collaboration
  - Licensing
  - All Strings had a GPS and Receiver

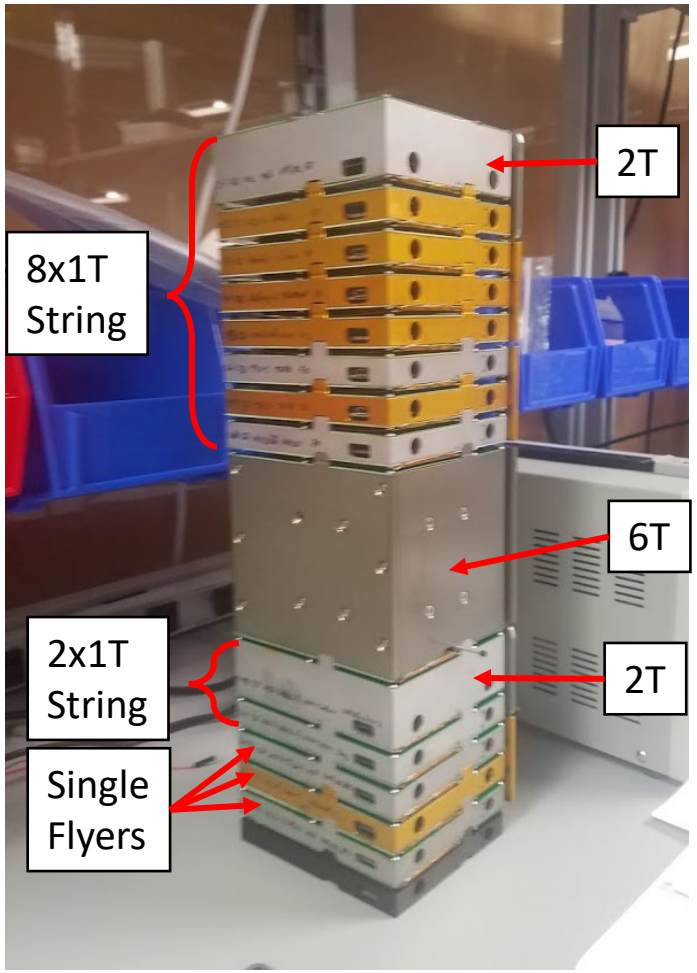


Bottom View



Top View

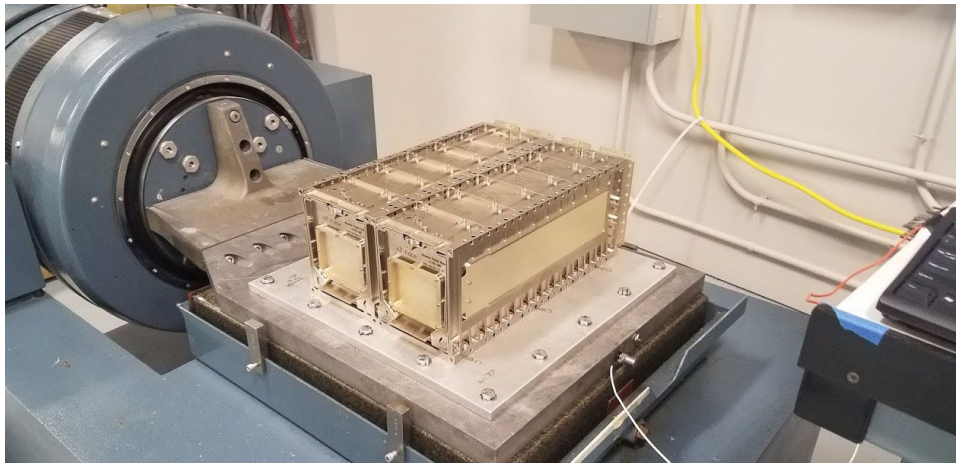
ThinSat-2 – Overview – Assembly & Testing



CSD-1 ThinSat Stack, for 3U launcher

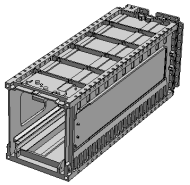
CSD-2

2 Cannisters in TVAC

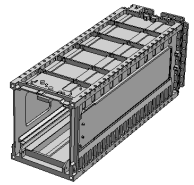


2 Cannisters in Vibration Testing

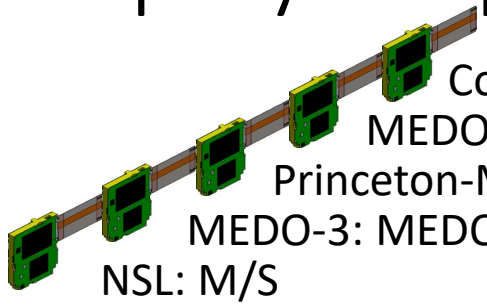
ThinSat-2 – Mission Results – Deploy Map



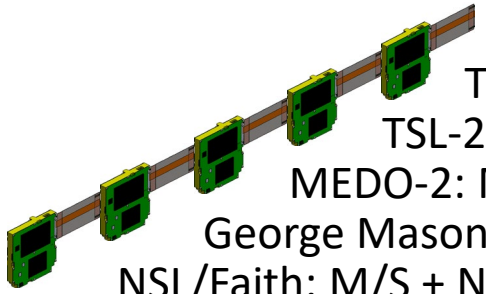
CSD-1 – 2nd to launch



CSD-2 – 1st to launch

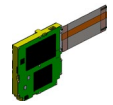


Coast Guard-2: NSE
MEDO-4: MEDO
Princeton-MEMs: Custom
MEDO-3: MEDO
NSL: M/S



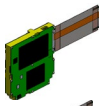
TSL-3 (Gamma): TSLPB + SB
TSL-2: TSLPB
MEDO-2: MEDO
George Mason U-1: Custom
NSL/Faith: M/S + NSE

Taylor U: Custom
MEDO-1: MEDO
TSL-1: TSLPB + SB
Old Dominion U: TSLPB + Custom
Coast Guard-1: TSLPB
NSL: M/S

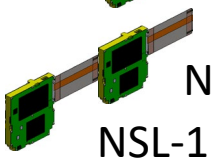


NSL-5 – U Minnesota: NSE

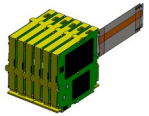
NSL-4 – Career: NSE



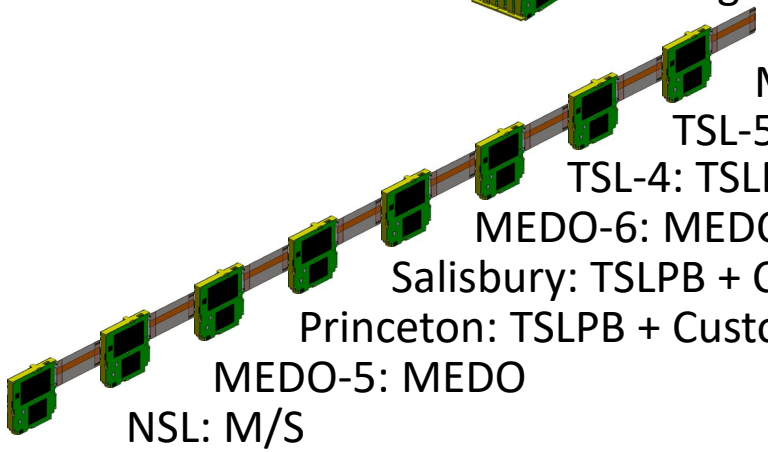
NSL-3 – Taylor: NSE



NSL-2 - AFRL: Custom
NSL-1 – AFRL: Custom



Virginia Tech: Custom



MEDO-7: MEDO
TSL-5: TSLPB
TSL-4: TSLPB + SB
MEDO-6: MEDO
Salisbury: TSLPB + Custom
Princeton: TSLPB + Custom
MEDO-5: MEDO
NSL: M/S

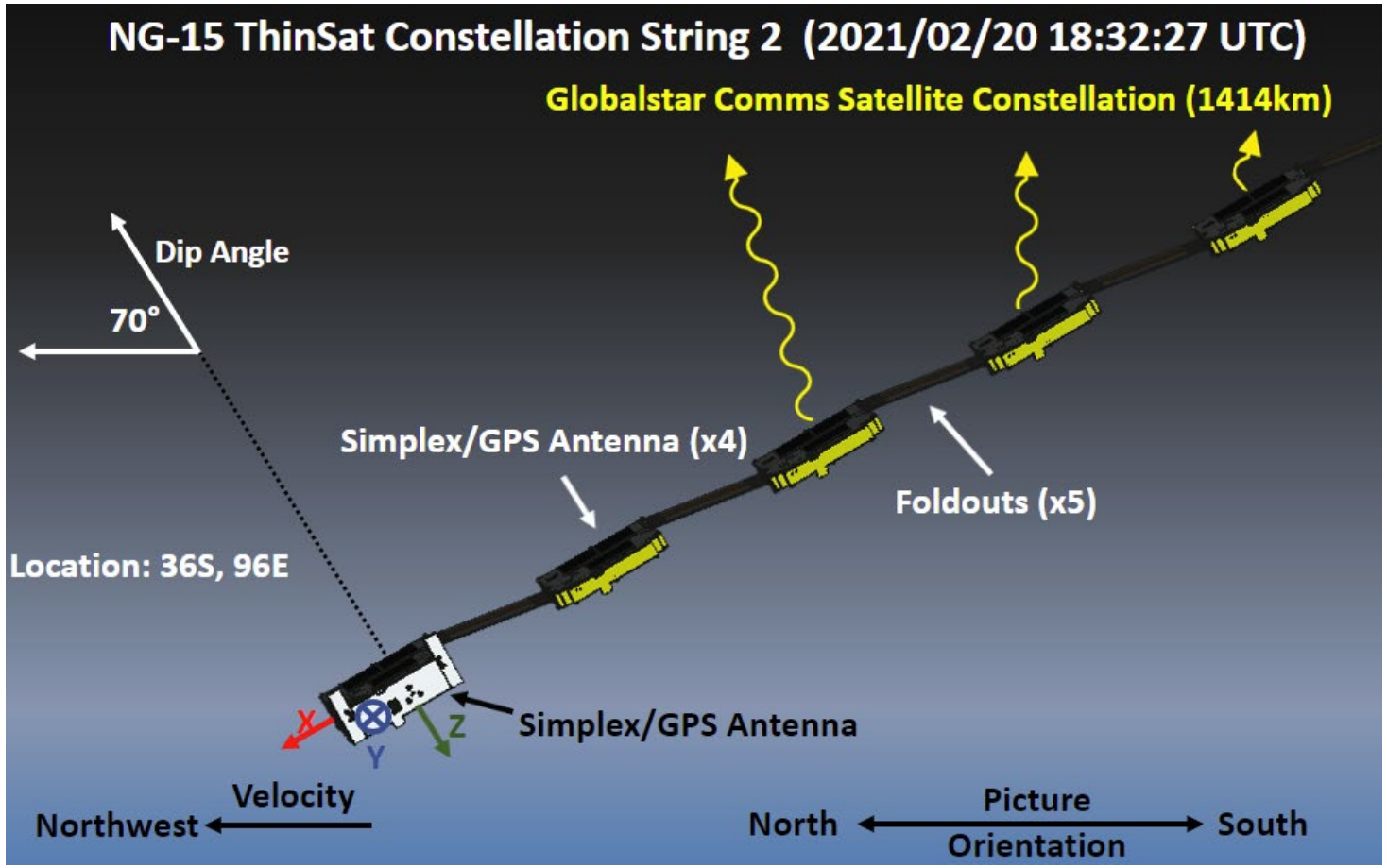
ThinSat-2 – Mission Results – NG-15 Successes

- Much STEM learning even in failure
- Achieved orbit
  - 180 x 260 km (1-3 day lifetime)
- 2 CSDs released
- 3 Mothership ThinSats turned on for short while
- Globalstar link worked well
- Based on 3 ThinSats that turned on, EPS, Solar, full Bus system worked well
- ThinSat data verified that battery voltage decaying rapidly
- Detumble and reaction wheel appear to be working, on all 3 ThinSats
- Student Sensor Boards worked well
  - 4 consistent Temps ~22C with cooling of 0.5 deg/min in eclipse
  - IMU, IR partial image: Gyro Low spin rate ~1 rpm
  - Light, UV and more info
- Battery Protection Circuit worked well so batteries off during launch
- Satellites appear to be working well as designed

ThinSat-2 – Analysis – Sensor Analysis

Preliminary Attitude Sensor Analysis

- Student Payload Board
- Lat. 36 S, over Indian ocean
- Dip angle = 70°
  - Horizon to earth's B-field
- Using 1 set of magnetometer data points
- Using location from TLE, we can correlate magnetometer data with known earth's magnetic field data
- Provides some good attitude determination
- Note that antennas and solar pointing up for good RF link and charging at this time



ThinSat-2 – Analysis – First Look at data

NearSpace Education (NSE) Team

In-Depth Analysis on a few payload sensor data points

Some first look sensor data from the Student Sensor Board (NSE) for one of the ThinSats. Packets viewing the night side of the earth, showing a single measurement per sensor.

Received Globalstar link Data 11 minutes after deployment over the remote South Atlantic Ocean.

Sensor	Reading	Sensor Location	Interpretation
Temperature 1	21.6 C [-40 - +125 C] (Cooling 0.8 deg C/min)	In-between UVA/UVC/Light to Frequency sensors and satellite frame	Board is around room temperature, which is not unexpected post-launch, given the significant atmospheric heating during launch.
Temperature 2	21.7 C [-40 - +125 C] (Cooling 0.9 deg C/min)	Middle of sensor board	Satellite was on the dark side of the Earth and cooling.
Temperature 3	22.3 C [-40 - +125 C] (Cooling 1 deg C/min)	In between IR sensor array and satellite frame	Thermal balance of ThinSats looks good (there isn't too much of a thermal gradient across the board).
UV A Light	6 mV [0 – 3.3 V] (increasing 1mV/min)	Upper left edge of sensor board	Indicates very low amounts of UV light, given calibration data. This is consistent on the night side of the Earth.
UV C Light	4 mV [0 – 3.3 V]	Upper left edge of sensor board	Low light level is consistent with being in eclipse.
Phototransistor	3 mV [0 – 3.3 V]	^	Indicates darkness, given calibration data (eclipse)
Light to Frequency	0 Hz [0 - 500 kHz]	^	Indicates darkness, given calibration data
Gyroscope X	4.24 deg/sec* or 0.67 RPM	Inside IMU near center of sensor board	Indicates slight change in rotation rates after the satellite was powered on in the deployment process, potentially from foldouts, ADACS, or some other source.
Gyroscope Y	0.68 deg/sec* or 0.113 RPM	^	^ Slow RPM is expected before ADACS detumble
Gyroscope Z	4.95 deg/sec* or 0.825 RPM	^	^
Accelerometer X	0 g	^	Satellite is in freefall, so this is expected.
Accelerometer Y	0 g	^	^
Accelerometer Z	0 g	^	^
Magnetometer X	-0.02 gauss	^	Normal levels for Earth's magnetic field
Magnetometer Z	-0.41 gauss	^	Normal levels for Earth's magnetic field
IR Sensor Array	Temperatures ranging from extreme cold to extreme hot	Lower left edge of sensor board	Sensor is observing the sun, the Earth's albedo and horizon, and the cold of space
Energetic particle detector	No packets received yet	Mid left region of sensor board	At this time, no packets related to the particle detector have been received.

*Relative to when the satellite was first powered as it was leaving the deployer

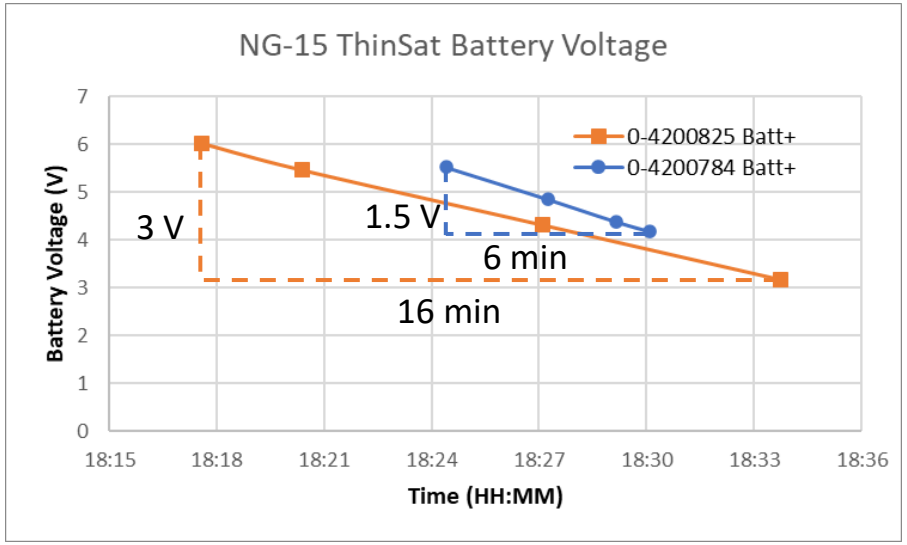
ThinSat-2 – Analysis – Known Data Points, and Problem Discovered

Known Data Points

- Due to discharged batteries, initial transmissions delayed 10 minutes while solar charging
- Out of 30 ThinSats, 3 transmitted data
- Out of ~2-day mission, data downlinked only over 1st 40 minutes
  - 1 exception 13 hours in, likely from solar charging

After investigation

- Issue found to be caused by <u>discharged batteries</u>
- Also found
  1. Good Globalstar link
  2. Nothing stuck in launch tube
  3. Foldouts worked properly

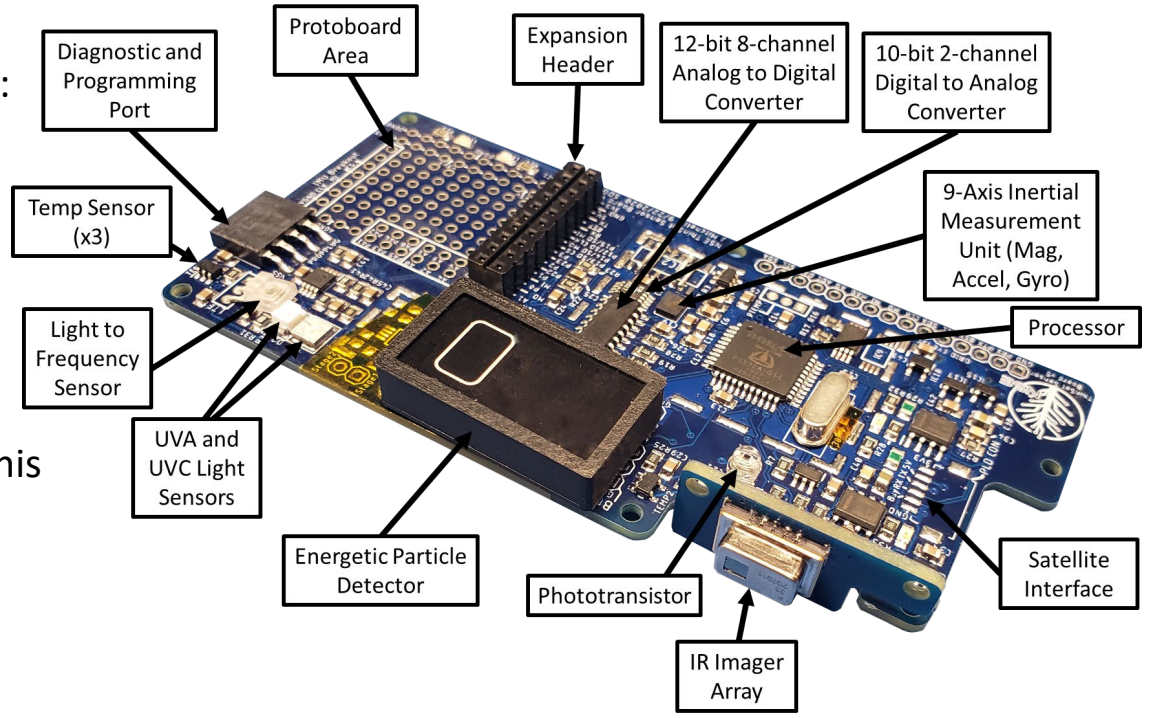


On Orbit Battery Voltage, showing sharp decline

ThinSat-2 – Analysis – Battery Problem

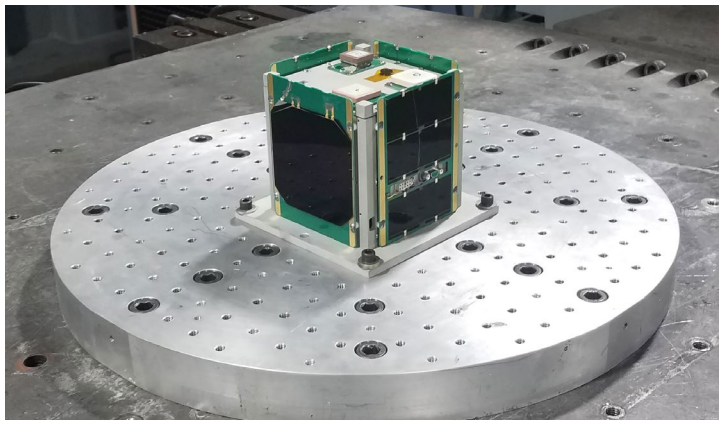
- Identified Source: Small leakage current in powered off ThinSats
  - Through a diode embedded in a solid-state relay IC
  - Large enough to cause most ThinSats to fully deplete over the 3 months before launch
- Through investigation, other issues were looked into and confirmed:
  - Batteries were delivered fully charged (no issue with NSL charging methods)
  - 6 month battery shelf life able to hold charge until launch
  - CSD doors were not opened after final charge event
  - Inhibit switches were validated
  - No ThinSats powered on in the launch tube
- More thorough ground testing would have easily caught and fixed this issue; did not perform same tests we did for NG-11 launch
- Given the poor ground testing which led to depleted batteries at launch, the ThinSat system performed well on orbit
- NSL is flying two NG-15 ThinSat Student Payloads on upcoming TROOP mission, with data made available to all ThinSat participants

NG-15 Student Payload onboard TROOP-2

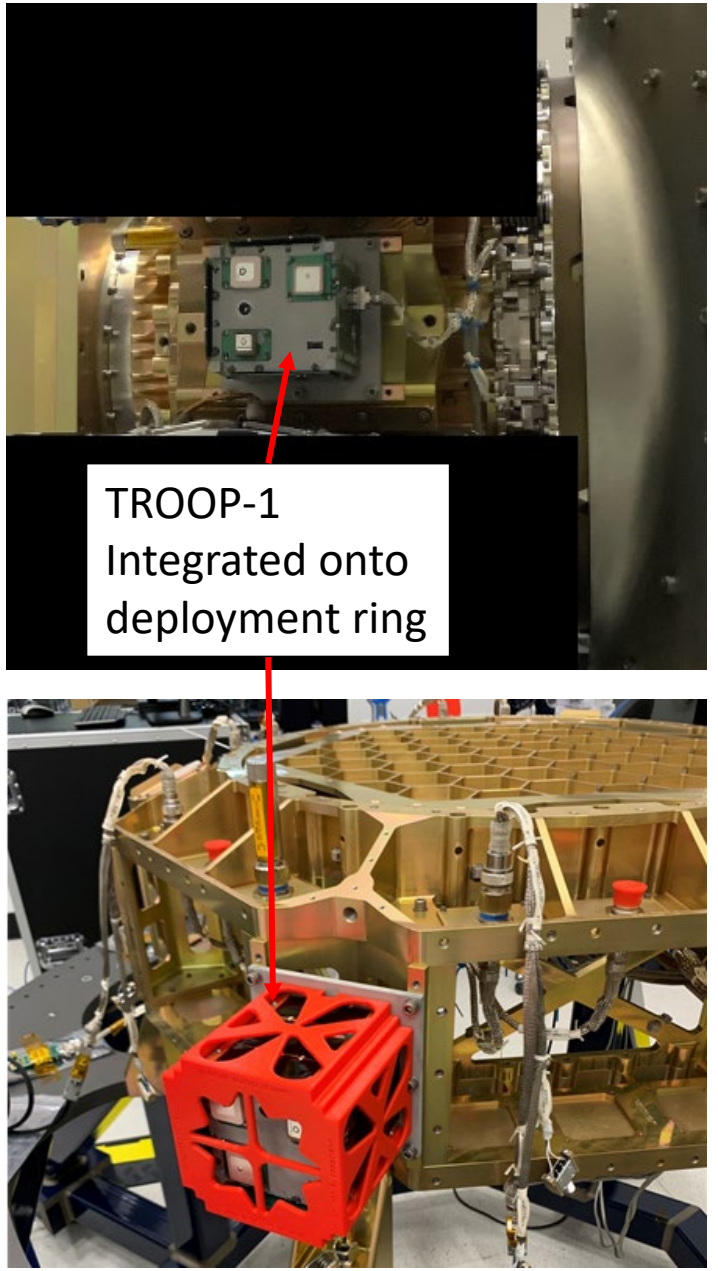


TagSat-1 (TROOP-1) Mission – Train Rapid On Orbit Payload

- Launched on Spaceflight, Inc.'s Transporter-1 rideshare launch on 1/24/2021
- Mounted to Spaceflight's SHERPA deployment ring
- Observed and downlinked separation events and GPS data for deployment ring
- Successfully ID'd and provided TLE for ring
- 7 year orbit life

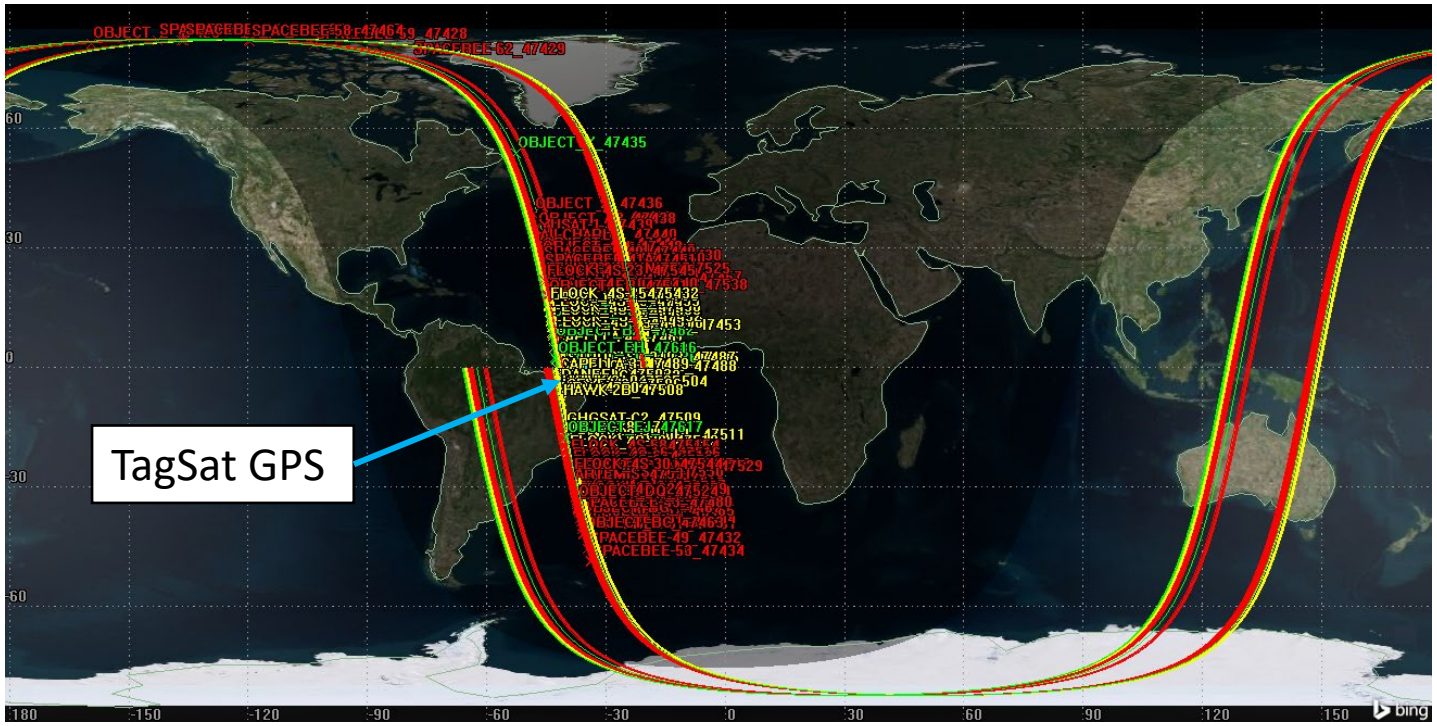


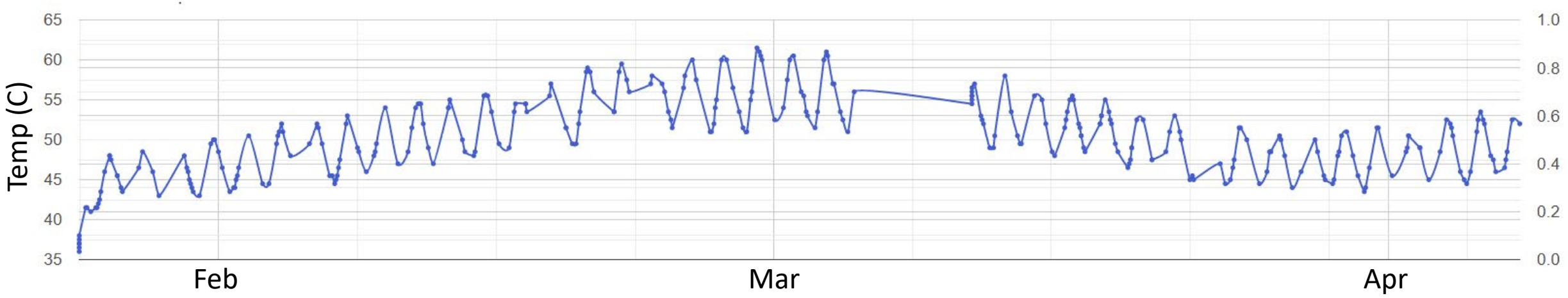
TROOP-1 during testing



TagSat-1 Results

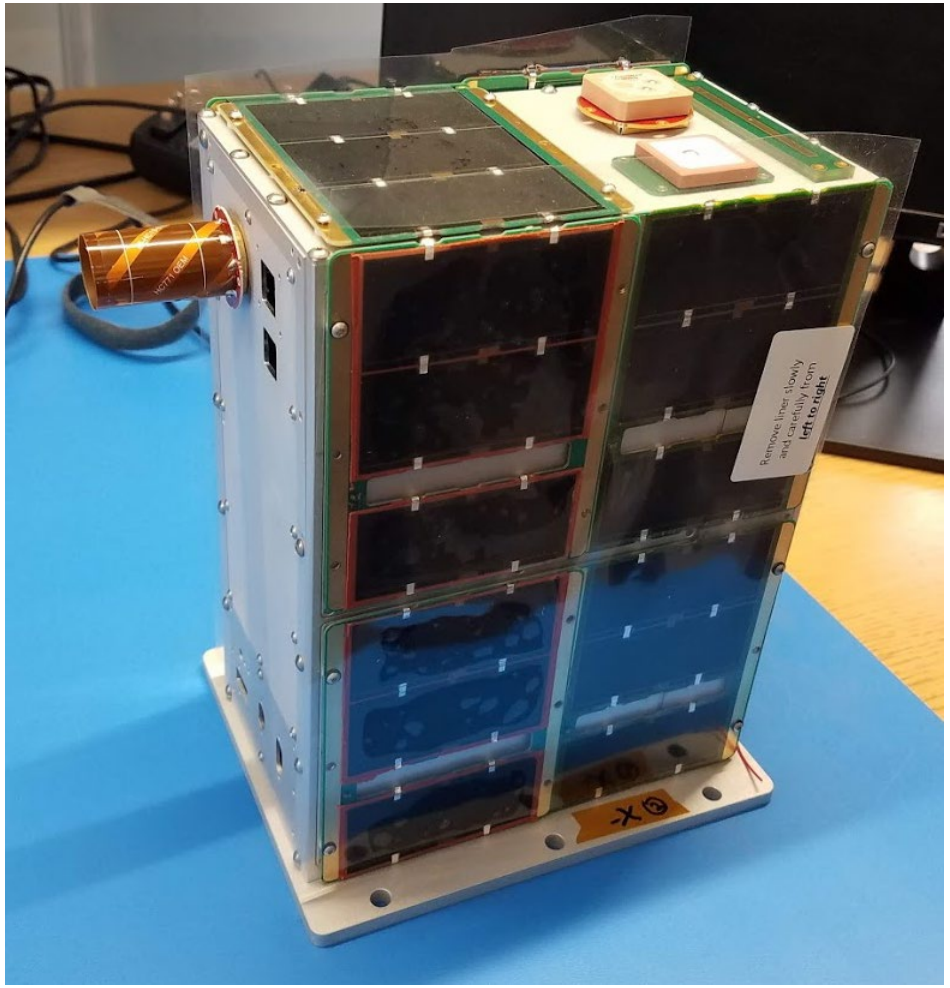
- New GPS, with 6 sat lock ->
  - Location and orbit tracking of TagSat-1, in cluster of other rideshare satellites, provided by the EyeStar-Tag soon after turn on
  - Satellite ID/TLE confirmed
- Temperature variation
  - Temperature data of TagSat-1
  - Showing spin and precession variations





TagSat-2 (TROOP-2) Mission – Train Rapid On Orbit Payload

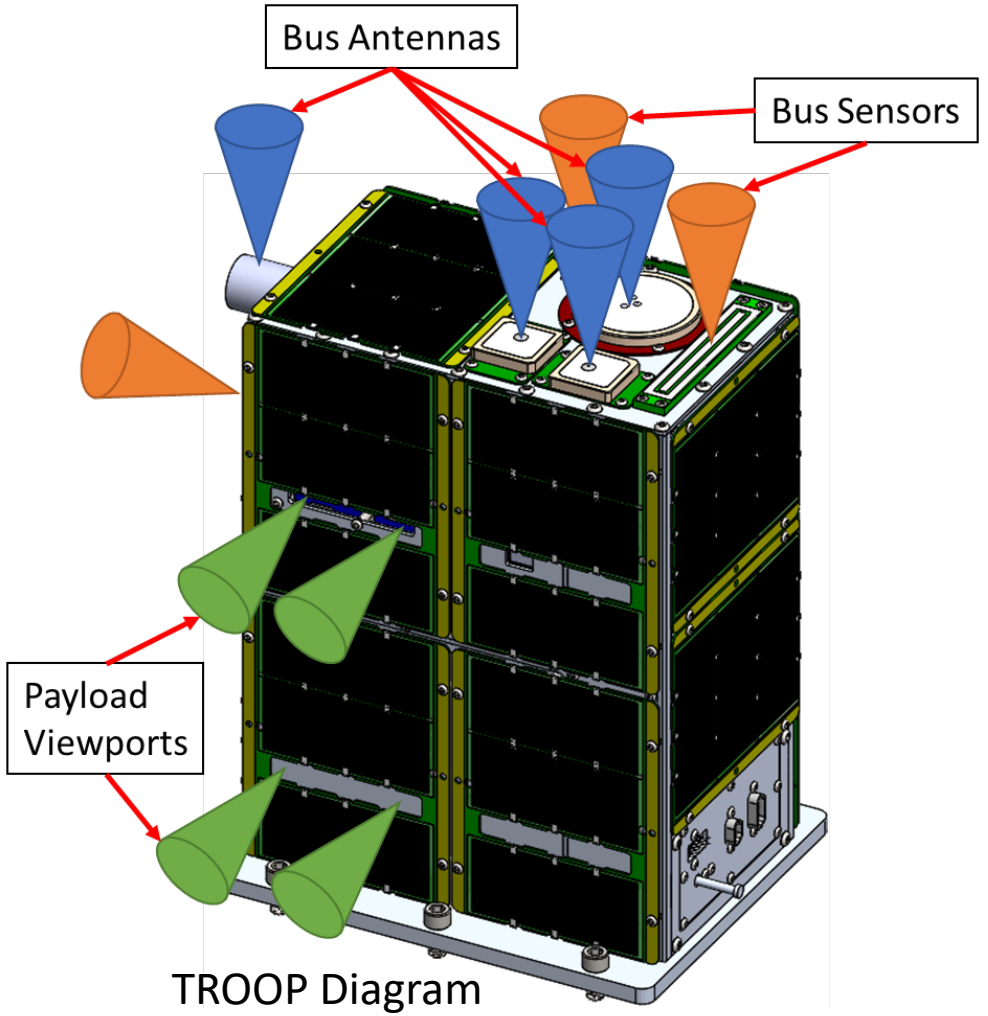
- Manifested to launch Spaceflight, Inc.'s Transporter-2 rideshare launch on 6/15/2021
- Mounts to deployment ring
  - TROOP Size: 22 x 16.8 x 9.9 cm
- Will observe and downlink separation events and GPS data
- Hosts four payloads
- Downlinks live payload data over the Globalstar network
- Up to 8 year orbit lifetime



TROOP-2 Assembly

TROOP System (Train Rapid On Orbit Payload)

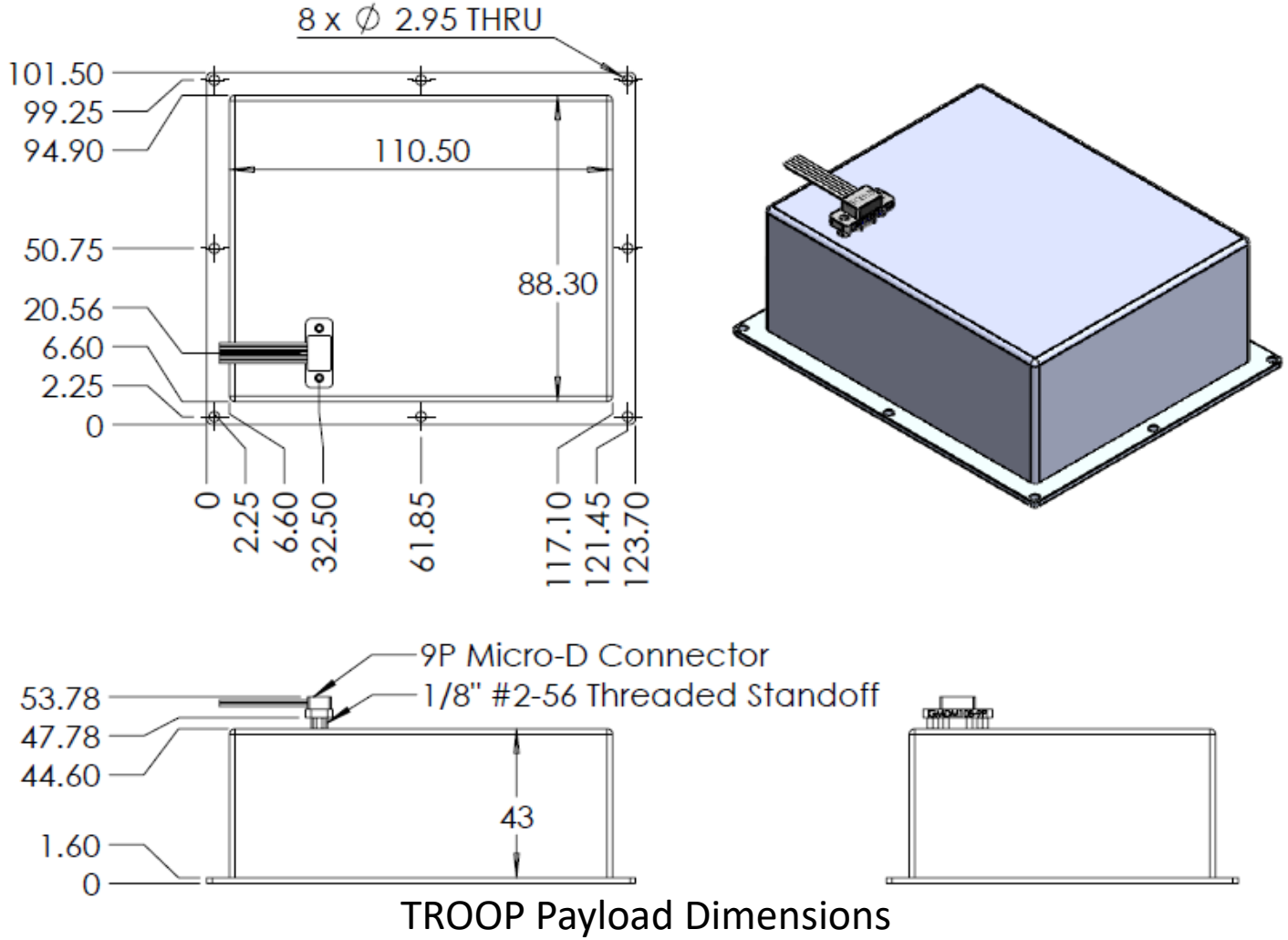
- Hosted Payload on Spaceflight, Inc. launch
- Hosts up to 4 payloads internally
- Launch cadence: 3-6 months
- Orbit Lifetime: ~8 years
- Cost: $80k/payload with flight Bus & Comms
- Bus Provided
  - Regulated Power & Simple Serial Interface
  - View Port to space
  - Live Streaming Data Downlink through Globalstar network
  - GPS Location
  - Online Data Access
  - Sensor data: Energetic Particle, Plasma, IMU
- Next launches
  - TROOP-2: June 2021 – Filled
  - TROOP-3: Dec 2021 – Slots still open
  - TROOP-4/5: 2022 – Slots still open



TROOP Diagram

TROOP System – Payload

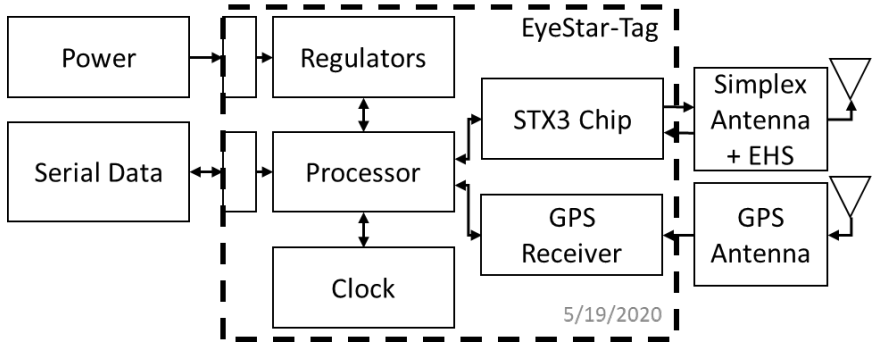
- Dimensions: 11 x 8.8 x 4.3 cm
- Mass: 500 g
- Power (1 A max total)
  - 5.0 V
  - 3.3 V
  - BUS+ (7-8 V)
- Interface
  - TTL
- Current Data Rate
  - 1,400 bytes/day
- Possible Future Data Rate
  - 23,000 bytes/day

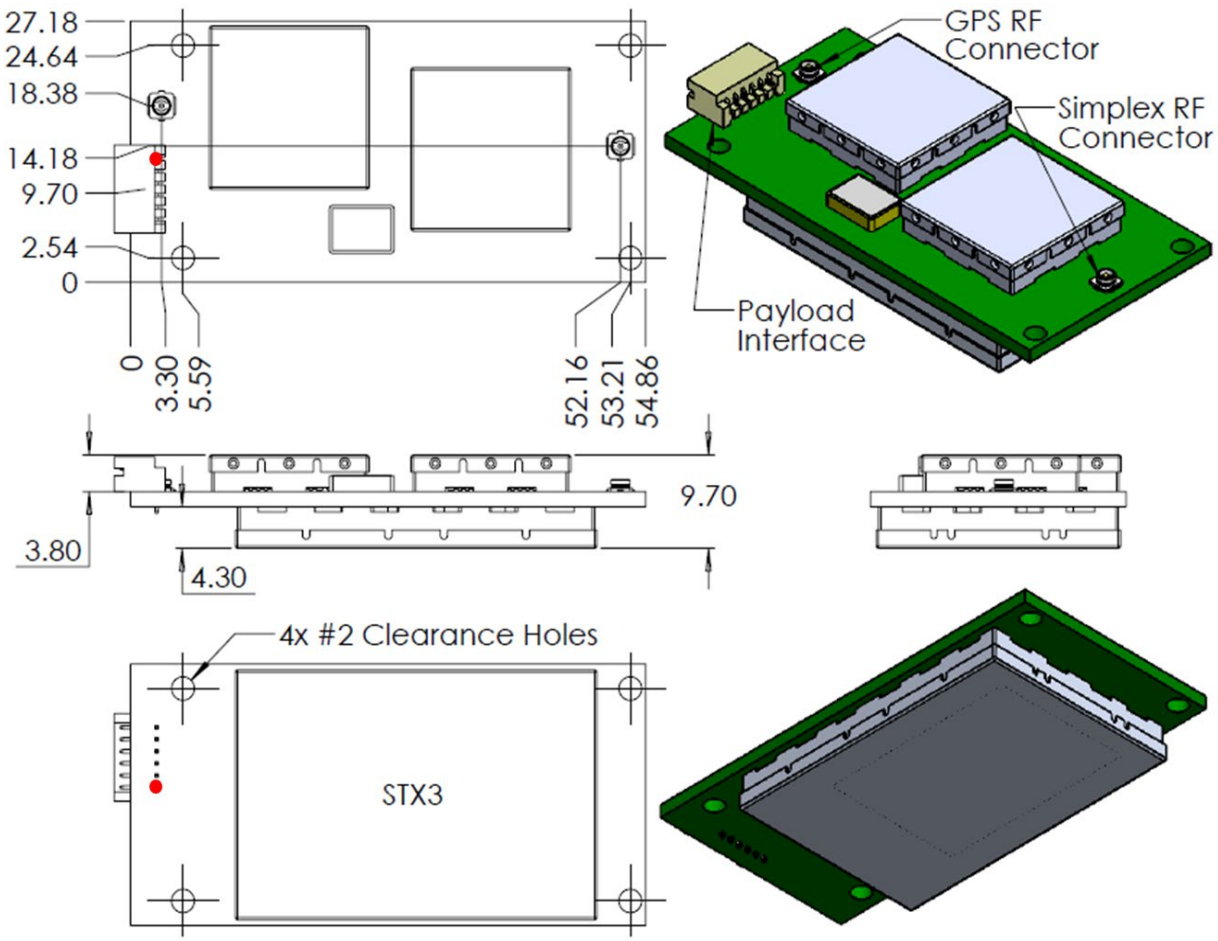


TROOP Payload Dimensions

For ID and Satellite Tracking with critical data downlink: EyeStar-Tag

- EyeStar-S3 with a GPS integrated into the board
- GPS miniaturized to only slightly increase board size and power
  - 5.5 x 2.7 x 1 cm
  - 1.6 W in TX mode
- TagSat-1 on-orbit flight results show good acquisition time & location accuracy





EyeStar-Tag Dimensional Drawing

Conclusion

1. The ThinSat-2 mission launched, with 30 satellites deployed in constellation
    1. Ground testing issue led to discharged batteries on deployment
    2. ThinSat system still performed well, able to turn on and collect some student data
2. TROOP system launched, with many more to come
    1. TagSat-1 (TROOP-1) proved system concept, still collecting good data
    2. TROOP-2 launches in June, hosting 4 payloads and 2 ThinSat Student Payload Boards
    3. TROOP-3/4/5 in development, with slots still available
3. Miniaturized GPS integrated onto EyeStar-S3
    1. EyeStar-Tag developed and launched in orbit
    2. Demonstration flight successful, with acquisition lock and good GPS data collected
    3. Provided TLE and ID for launch ring
4. Upcoming Missions
    1. All missions mentioned in upcoming 2021
    2. TROOP-2/3/4/5
    3. FastBus CubeSats – DUPLEX, GEARRS3, CapSat-1, MESAT-1, …
    4. 300+ NSL Systems, including 50+ radios
    5. Other