Integration, Launch, and First Results from IDEASSat/INSPIRESat-2 – A 3U CubeSat for Ionospheric Physics and Multi-National Capacity Building

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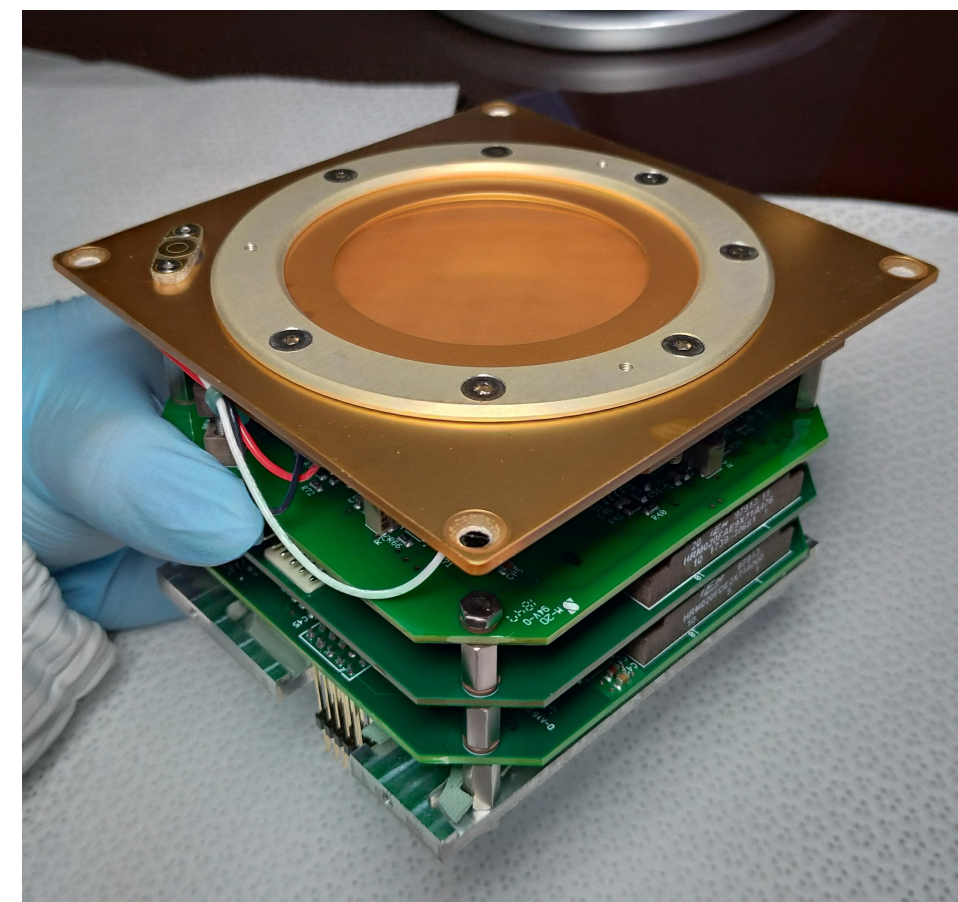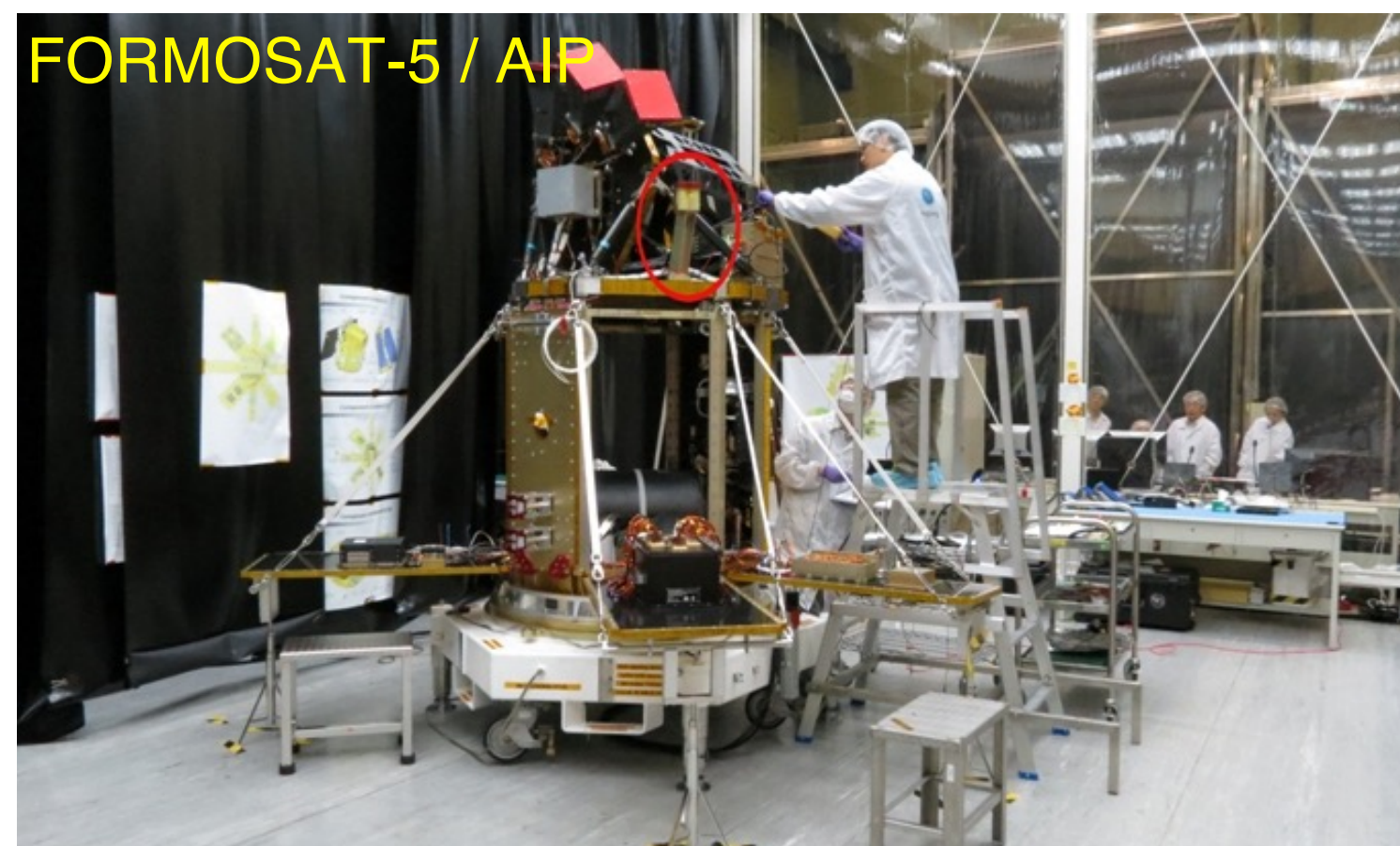[2] LETSCOM International, Ltd., Taiwan
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Payload:
Compact Ionospheric Probe (CIP)

FORMOSAT-5 / AIP
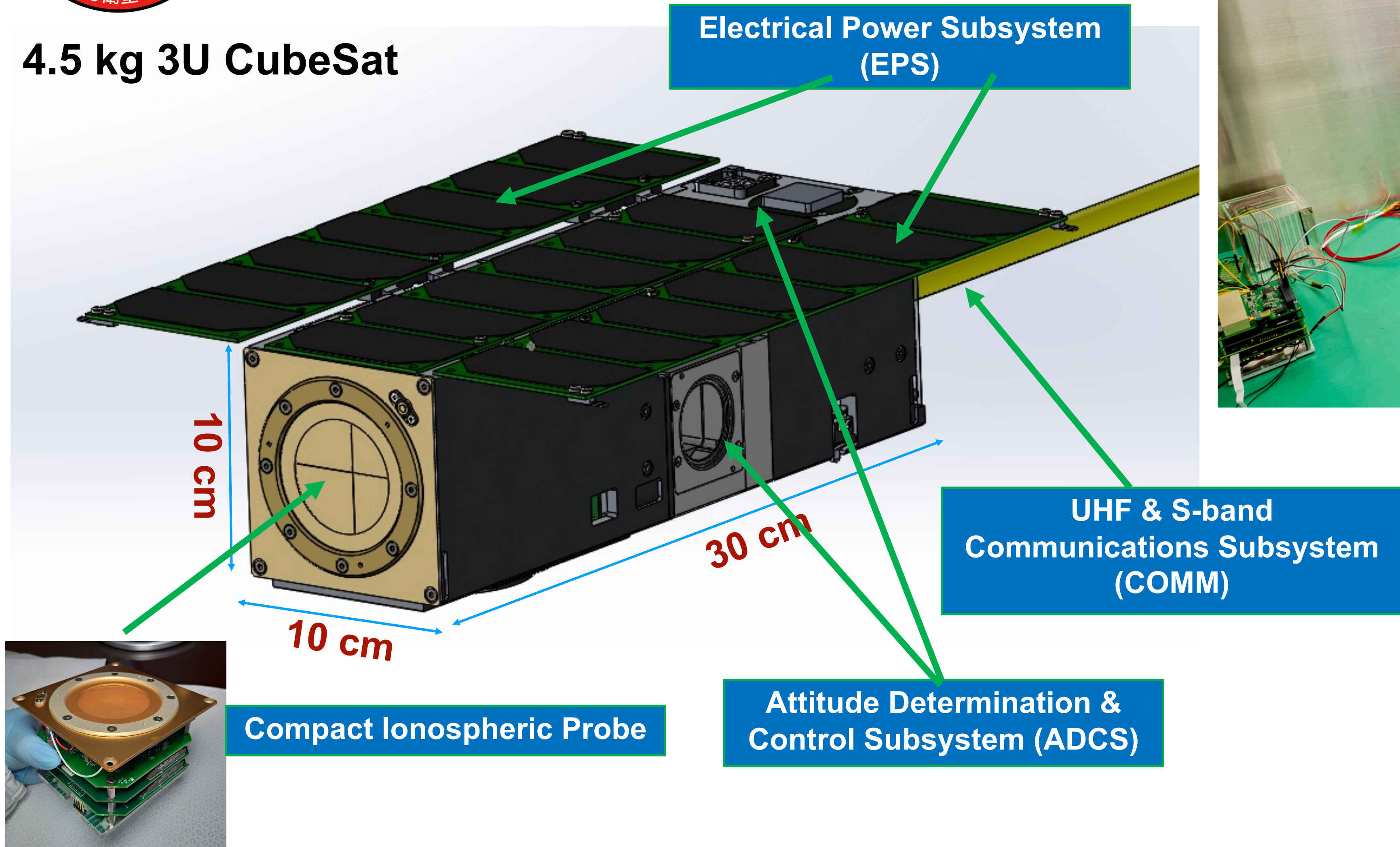

Mass & Volume	0.47 kg, 0.72U
Power	Peak: 5 W Nominal: 3.84 W
Data Interface	UART serial data bus in a Modbus-like protocol. RS-422 encoding.
Data Rate (100% duty cycle)	Normal: 24.1 MB day^{-1} Fast: 193.5 MB day^{-1}
Pointing Knowledge	< 0.25°, all axes.
Pointing Control	Aperture facing ram direction < 0.25°, all axes.

- FORMOSAT-5 AIP miniaturized by moving supporting electronics into sensor head.

  - AIP: Active on orbit since 2017/09.

- All-in-one multifunction in-situ plasma sensor:

  - **Retarding Potential Analyzer**:
    Ion temperature, composition, ram speed.

  - **Ion Drift Meter**:
    Plasma arrival angle.

  - **Ion Trap**:
    Ion density.

  - **Planar Langmuir Probe**:
    Electron temperature.

Motivation for development of first NCU spacecraft: IDEASSat (Ionospheric Dynamics Explorer and Attitude Subsystem Satellite)
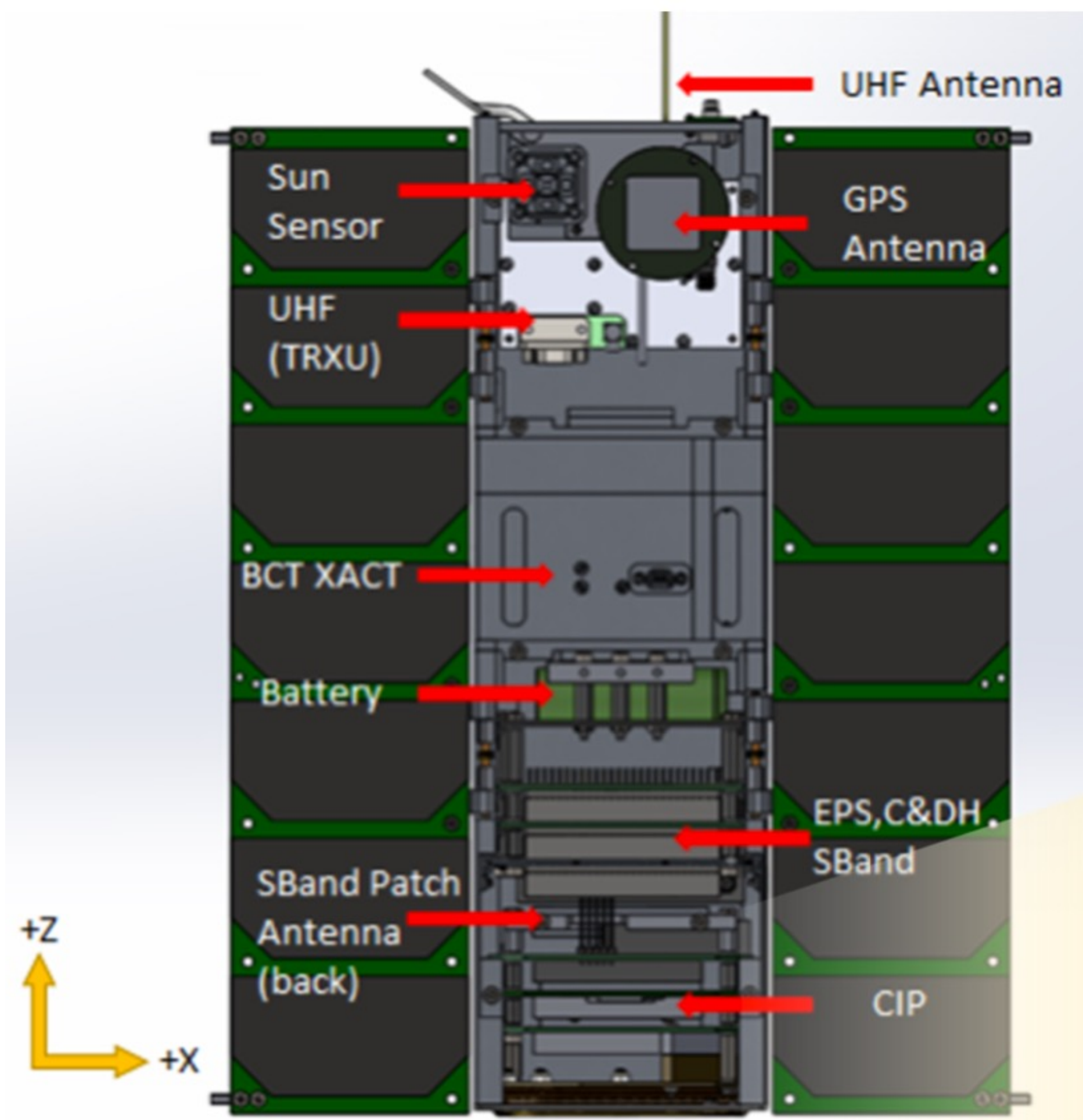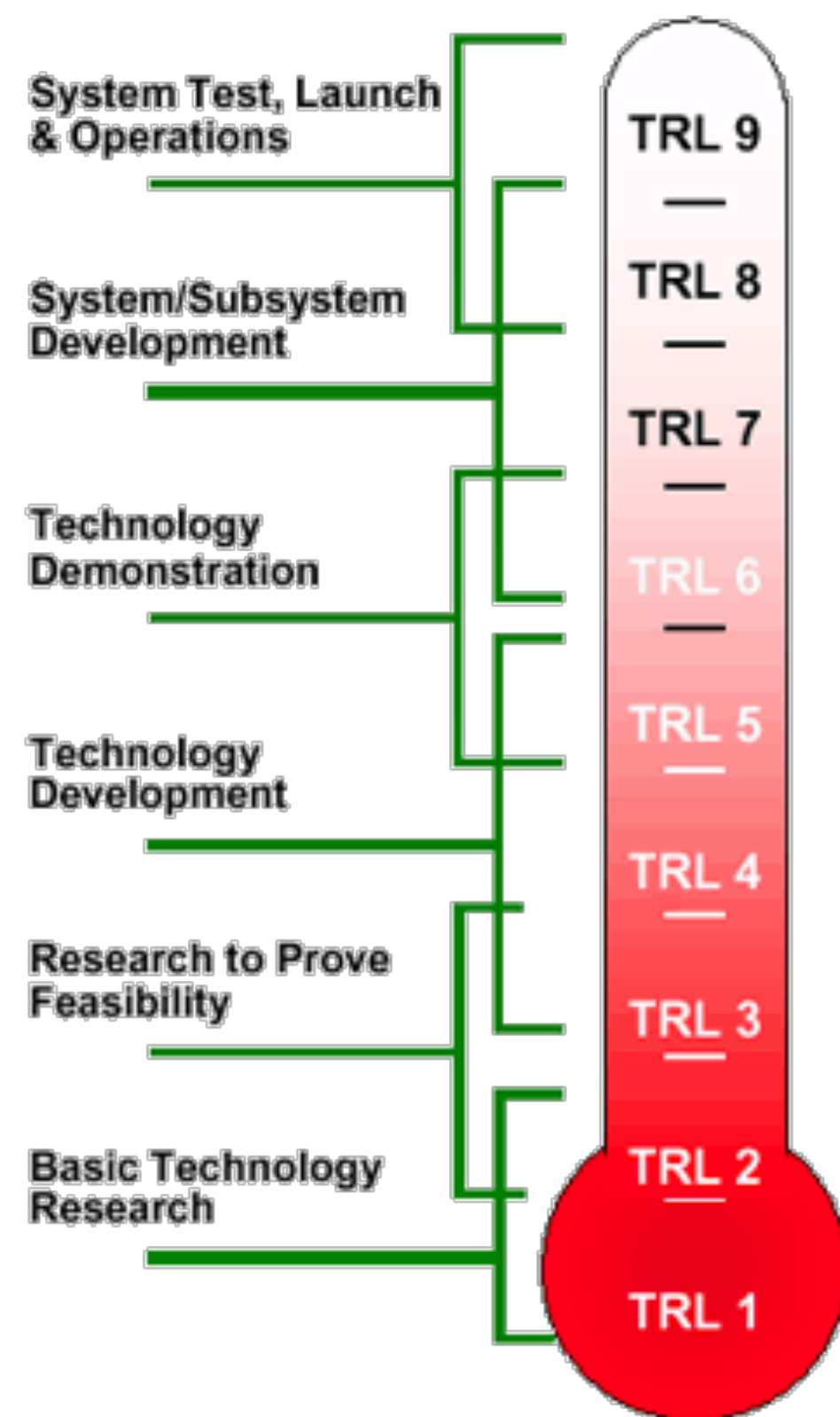
IDEASSat / INSPIRESat-2

4.5 kg 3U CubeSat

Electrical Power Subsystem (EPS)

UHF & S-band Communications Subsystem (COMM)

Attitude Determination & Control Subsystem (ADCS)

Compact Ionospheric Probe

10 cm

30 cm

10 cm

Orbit	500 km Sun Sync.
Mass / Volume	4.5 kg / 3U
Development	2017 – 2020 2 yrs + 1 yr extension
Launch	2021/01/24 SpaceX Falcon 9

IDEASSat System Overview

Subsystem	Solution	TRL
ADCS	Blue Canyon Technologies XACT with GPS	9
COMM (UHF transceiver)	SpaceQuest TRX-U	9
COMM (UHF Antenna)	Deployable monopole antenna	9
COMM (S-band transmitter)	CPUT STX-01-0017	9
EPS (Battery & Control PCBs)	NCU EPS	8
	18650 Li-ion batteries	9
EPS (Solar Cells)	AzurSpace TJ Solar Cell Assembly 3G30A	9
CDH (On Board Computer and Flight Software)	NCU CDH Interface Board	9
	Microsemi SmartFusion2 System-on-Module	9
STR	NCU 3U bus	9

Designed at NCU / Manufactured in Taiwan
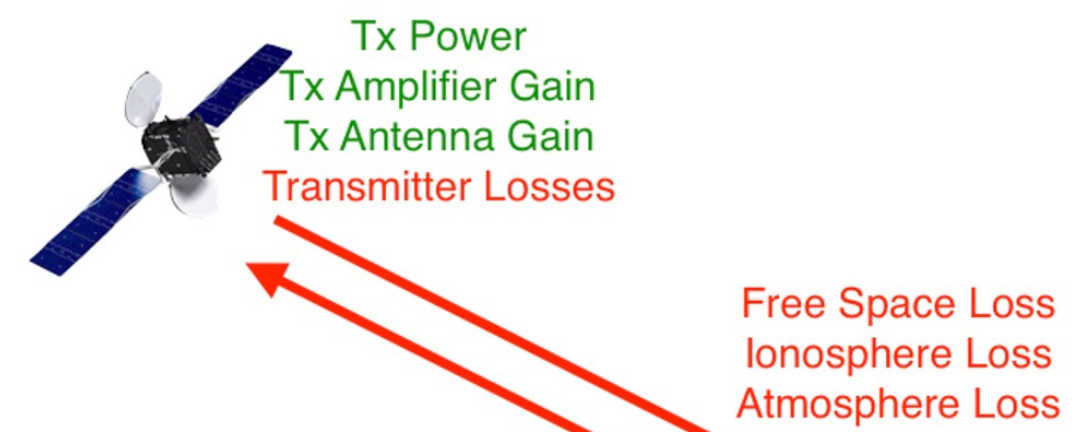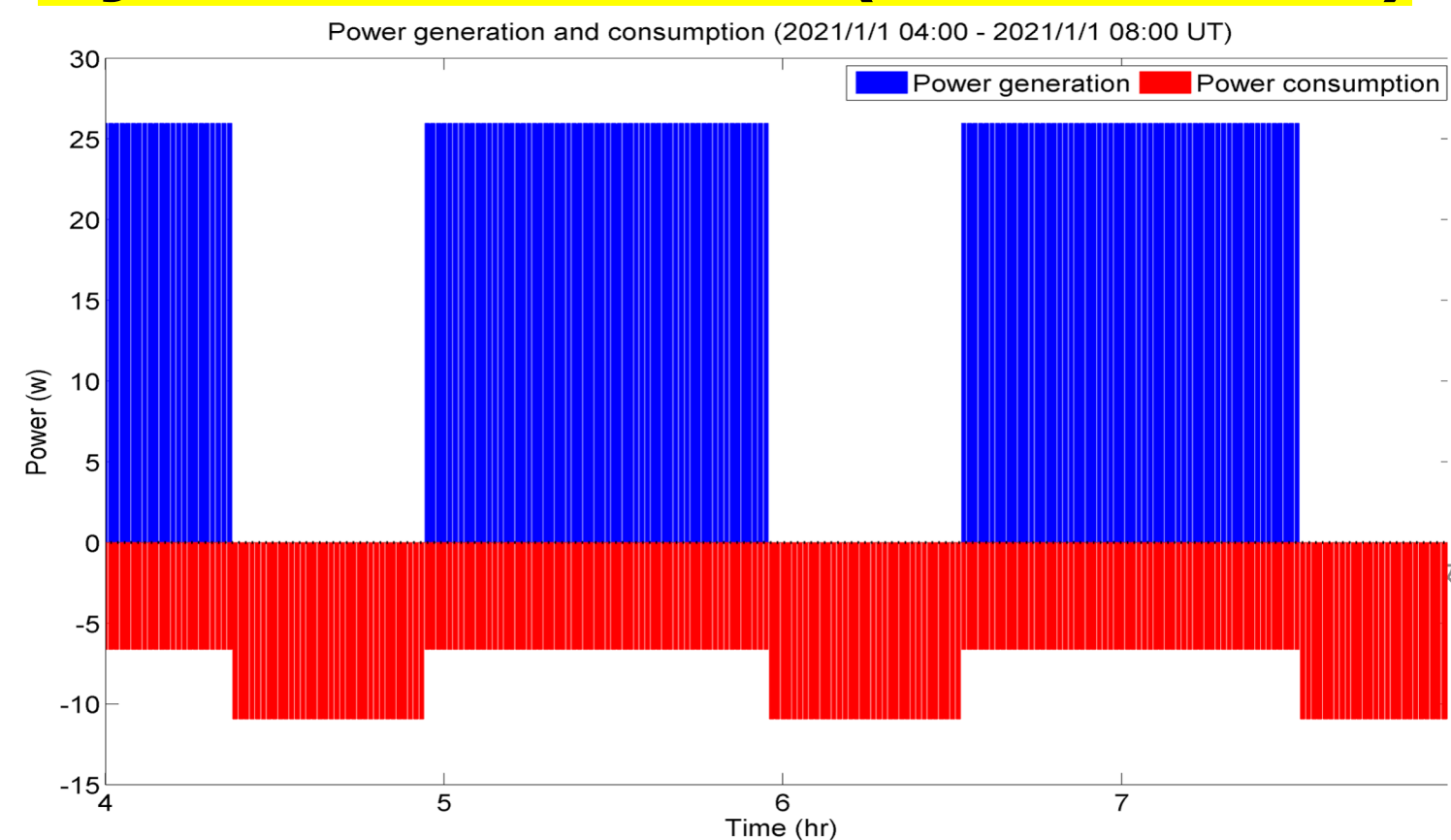
Technological Readiness Level (TRL)

System Test, Launch & Operations — TRL 9

System/Subsystem Development — TRL 8, TRL 7

Technology Demonstration — TRL 6

Technology Development — TRL 5, TRL 4

Research to Prove Feasibility — TRL 3

Basic Technology Research — TRL 2, TRL 1

+Z
+X

Sun Sensor
UHF (TRXU)
BCT XACT
Battery
SBand Patch Antenna (back)
UHF Antenna
GPS Antenna
EPS,C&DH
SBand
CIP

IDEASSat Flight Software

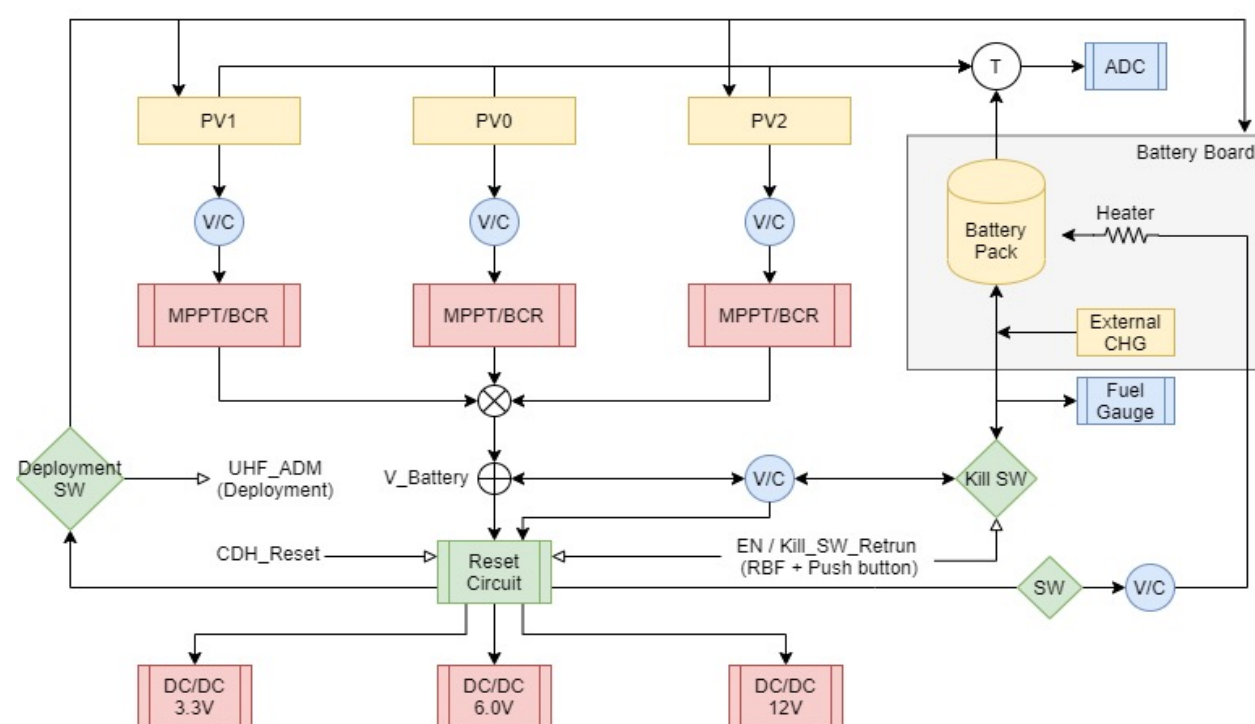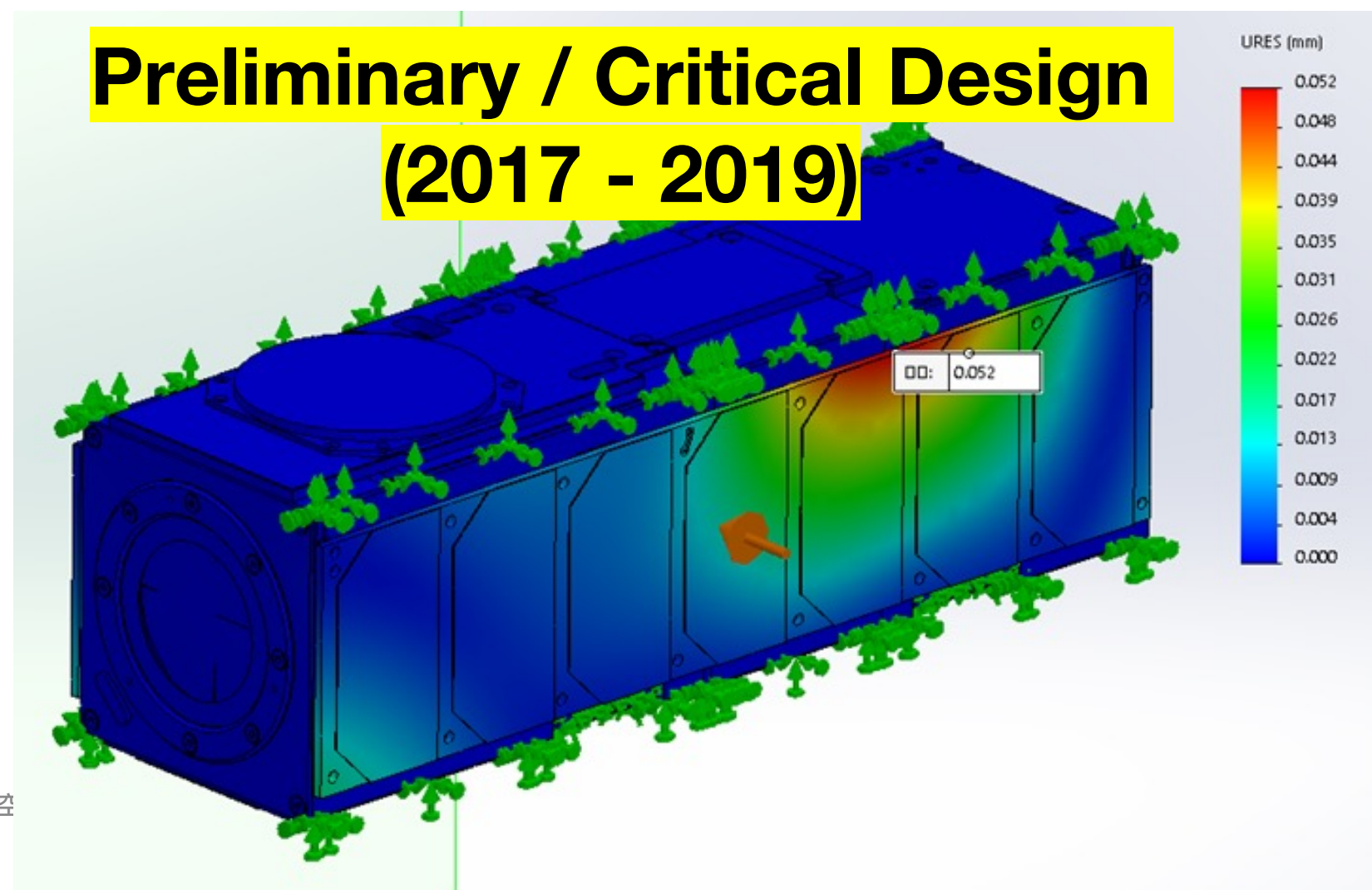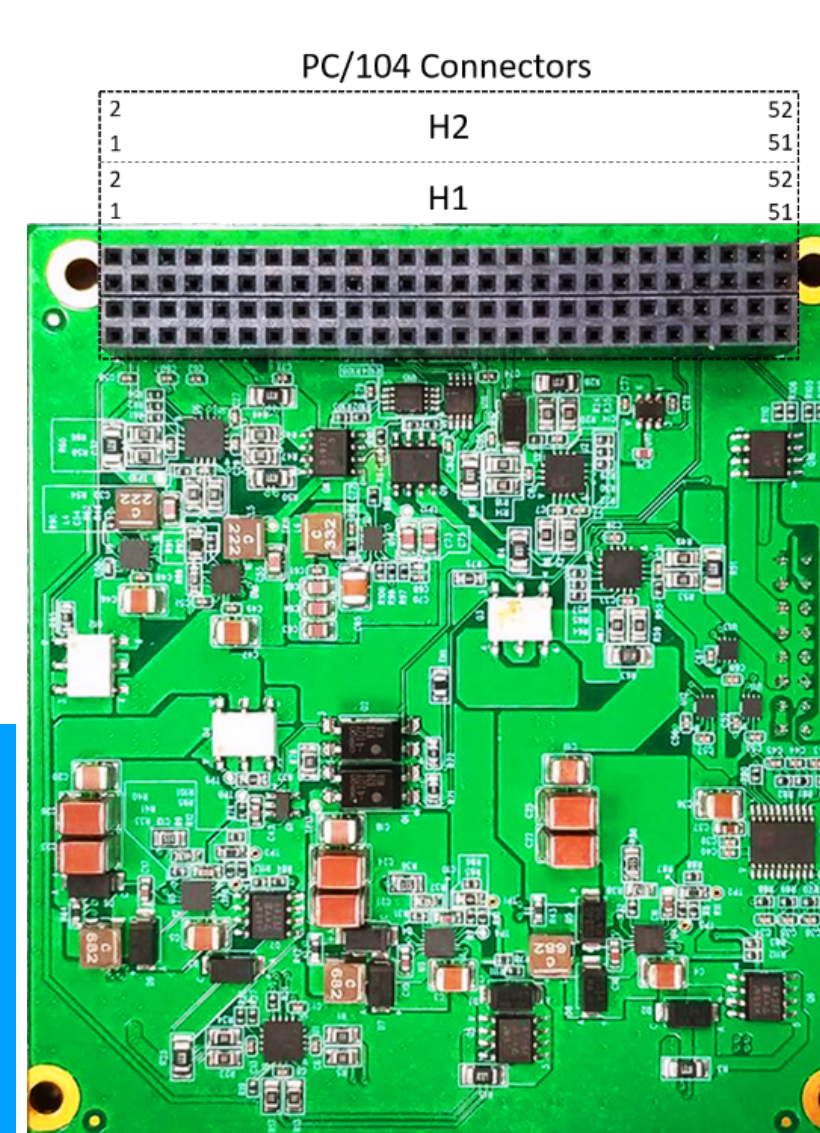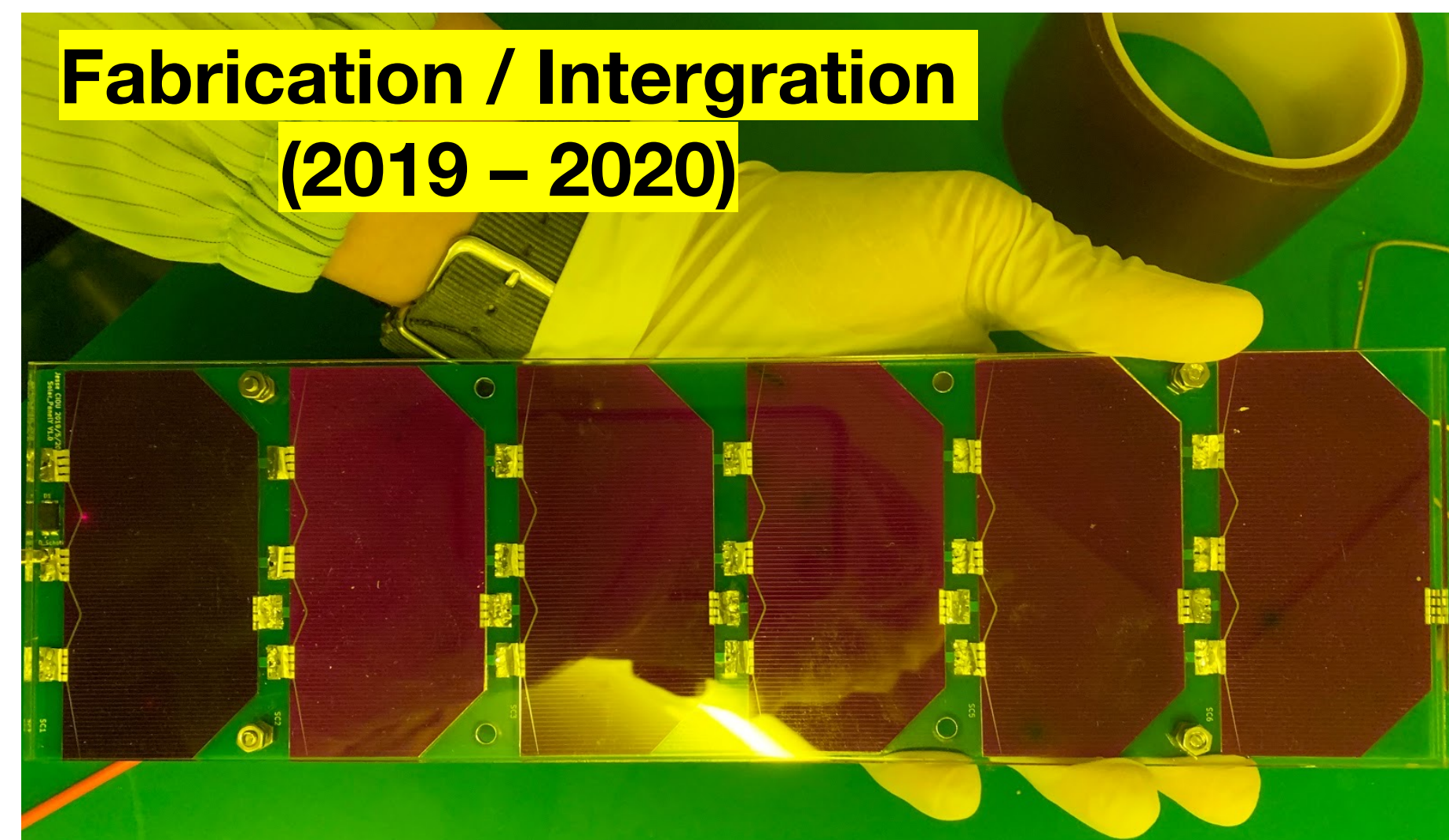| IDEASSat Operational Modes					
Mode	**EMERGENCY**		**NOMINAL**		
State	**Phoenix**	**Safe**	**Charging**	**Science**	**Transition**
EPS	ON	ON	ON	ON	ON
ADCS	OFF	Sun Point	Sun Point	LVLH	LVLH
CDH	ON	ON	ON	ON	ON
UHF(Tx)	BEACON	BEACON	BEACON	BEACON	BEACON
UHF(Rx)	ON	ON	ON	ON	ON
S-Band(Tx)	OFF	OFF	AS REQ	AS REQ	OFF
CIP	OFF	OFF	OFF	ON	OFF
Battery Heater	AS REQ	AS REQ	AS REQ	AS REQ	AS REQ
Avg. Power Required	2.18 W	5.0 W	13.79 W		
Avg. Power Generated	2.18 / 2.42 W Undeployed / Deployed	14.52 W	14.52 W		
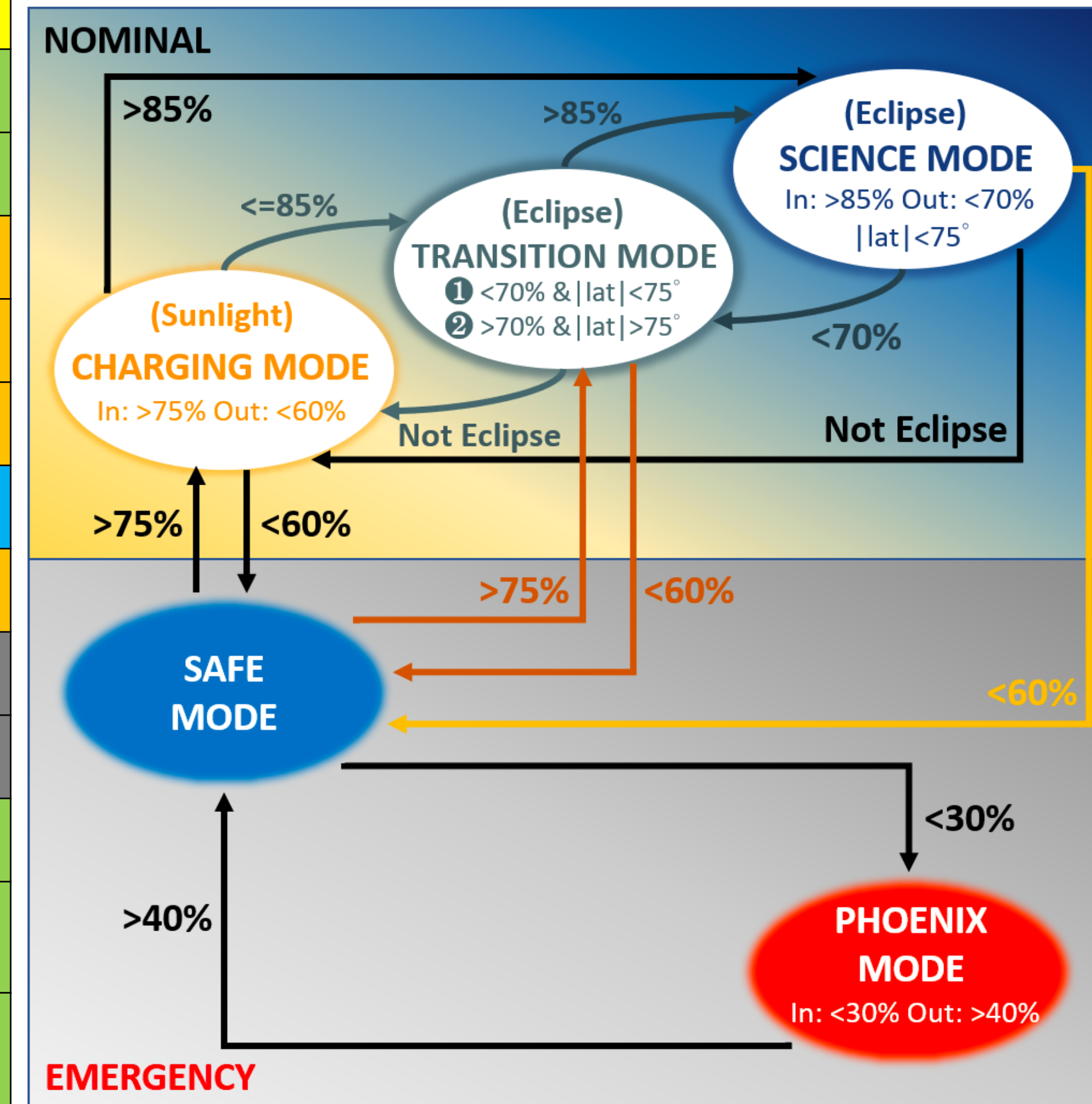
Spacecraft Development Process

Mission Concept / System Definition (2017 – 2018)

Preliminary / Critical Design (2017 - 2019)

**Fabrication / Intergration (2019 – 2020)**

Power generation and consumption (2021/1/1 04:00 - 2021/1/1 08:00 UT)

Tx Power
Tx Amplifier Gain
Tx Antenna Gain
Transmitter Losses

Free Space Loss
Ionosphere Loss
Atmosphere Loss

Lessons Learned:
Hardware development and debugging is like software, only with each iteration requiring more time and money!
Subsystems can work well individually only to fail when integrated.
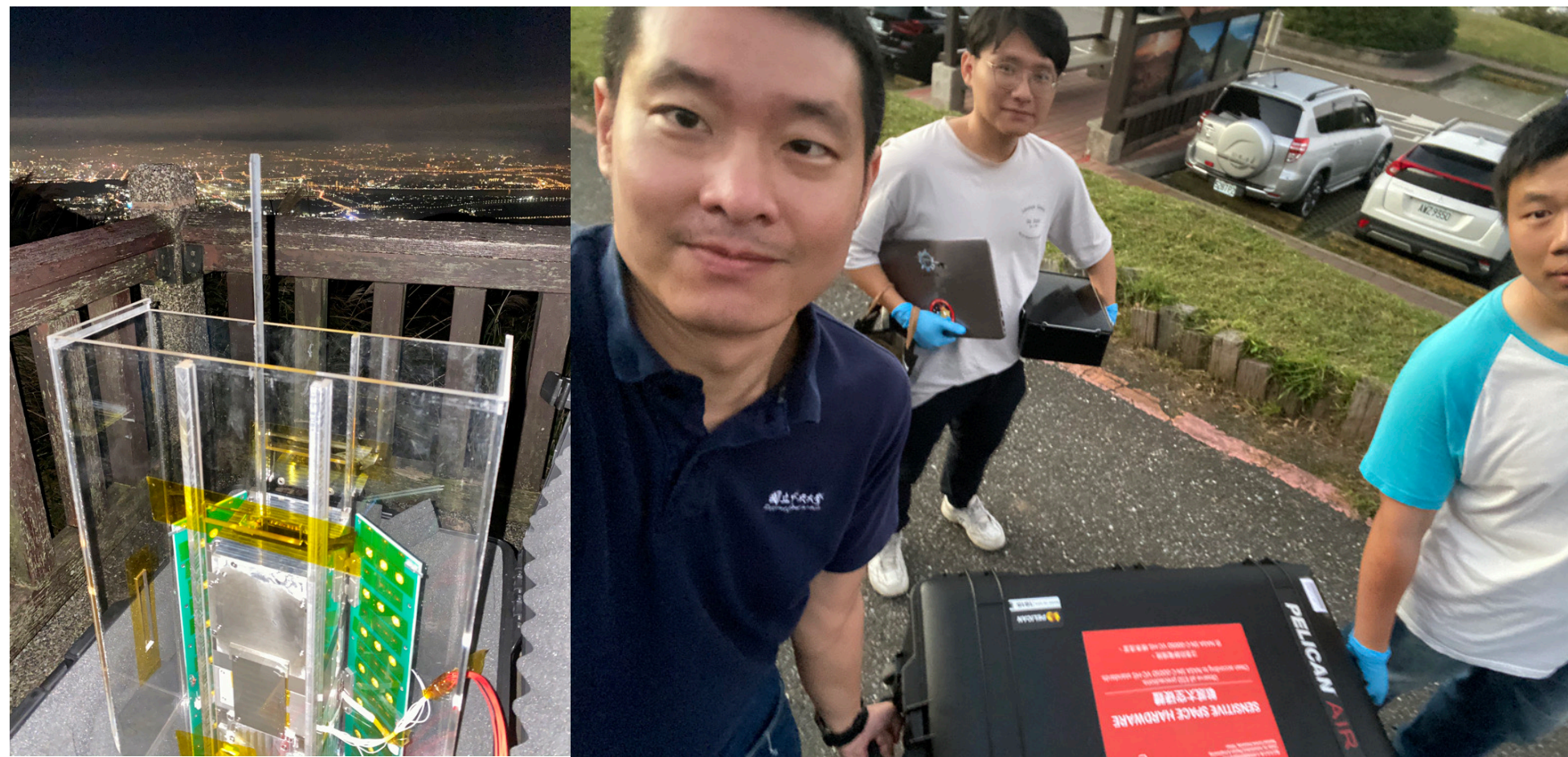
Testing (2020/08 – 11)
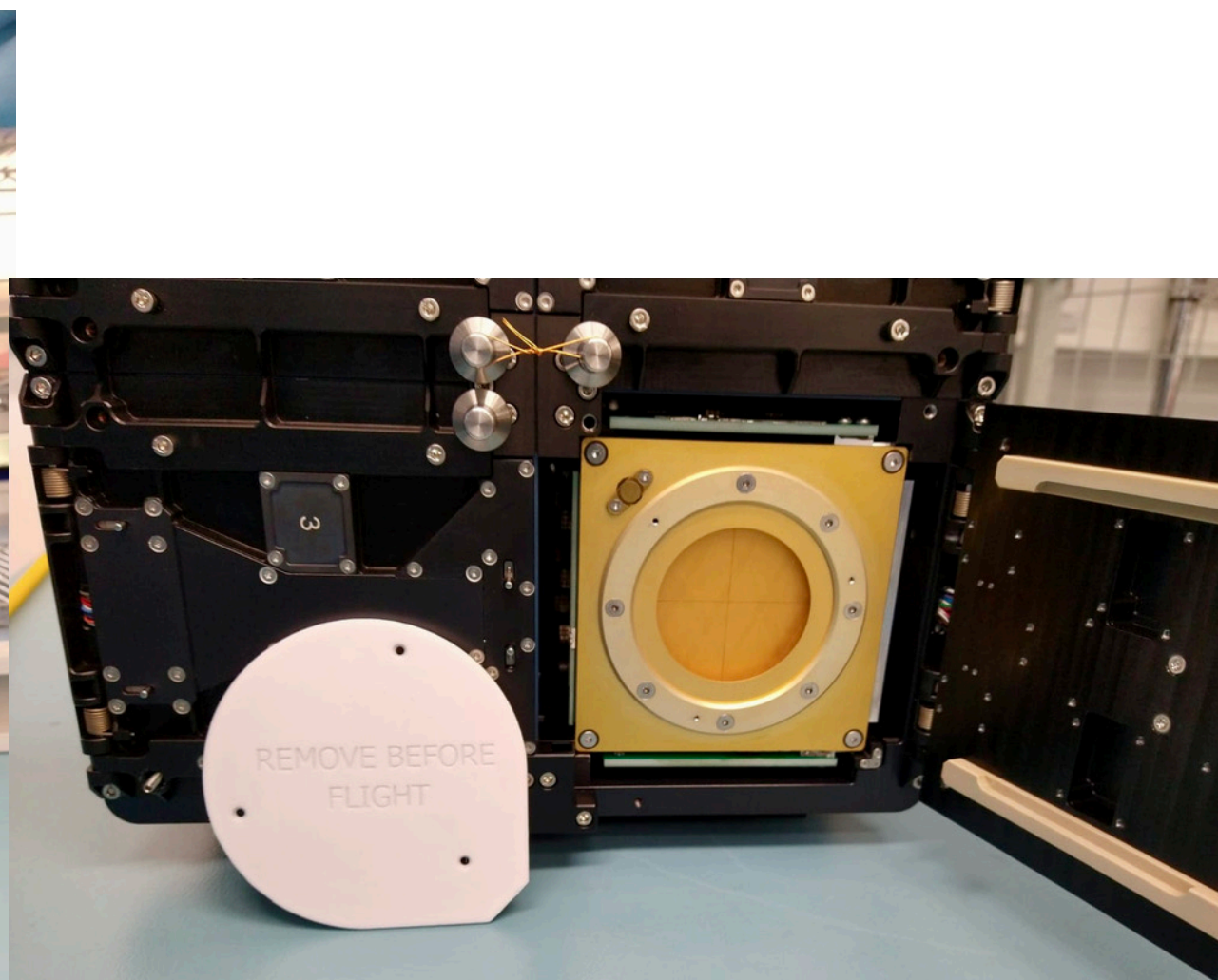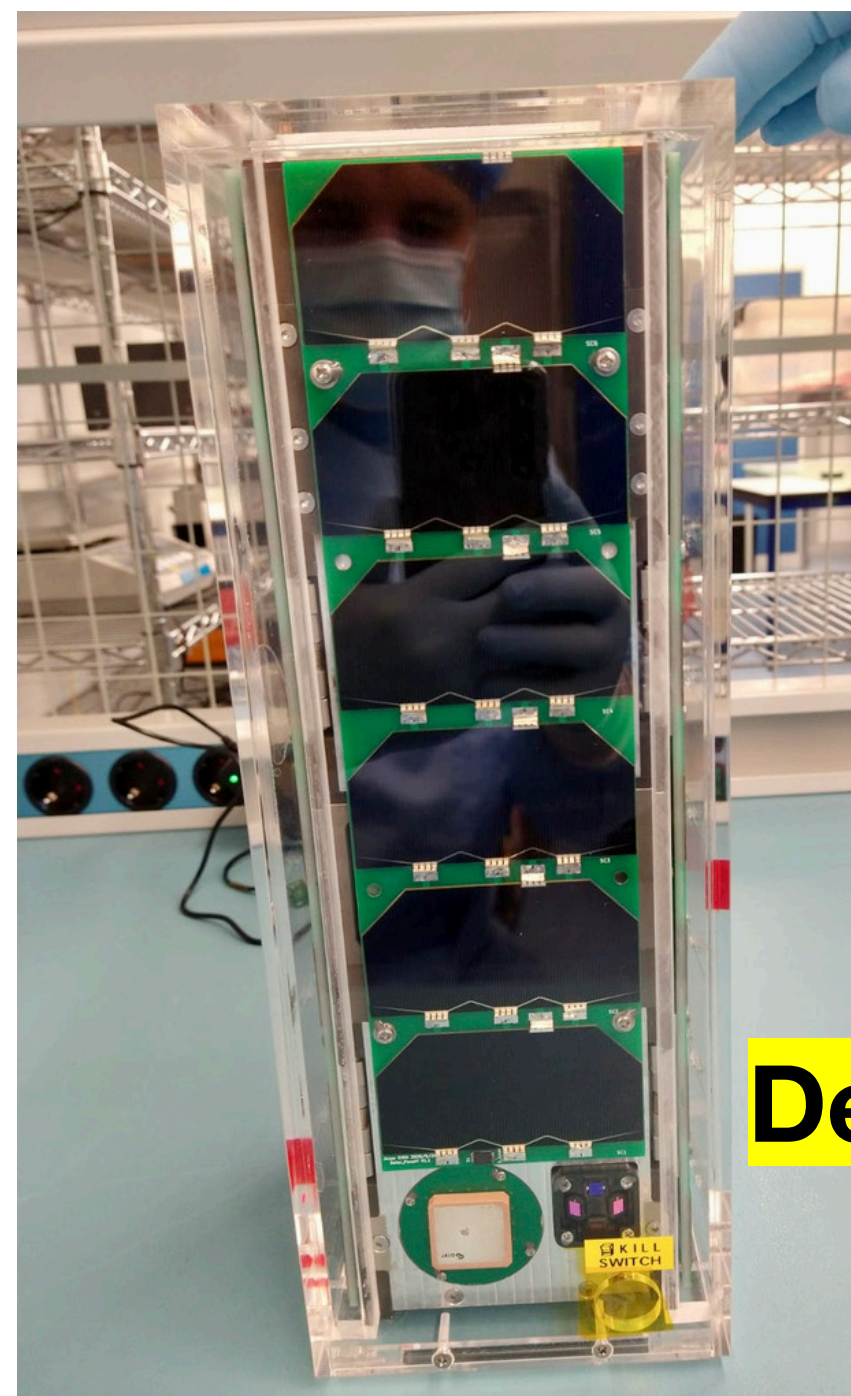
Thermal Vacuum
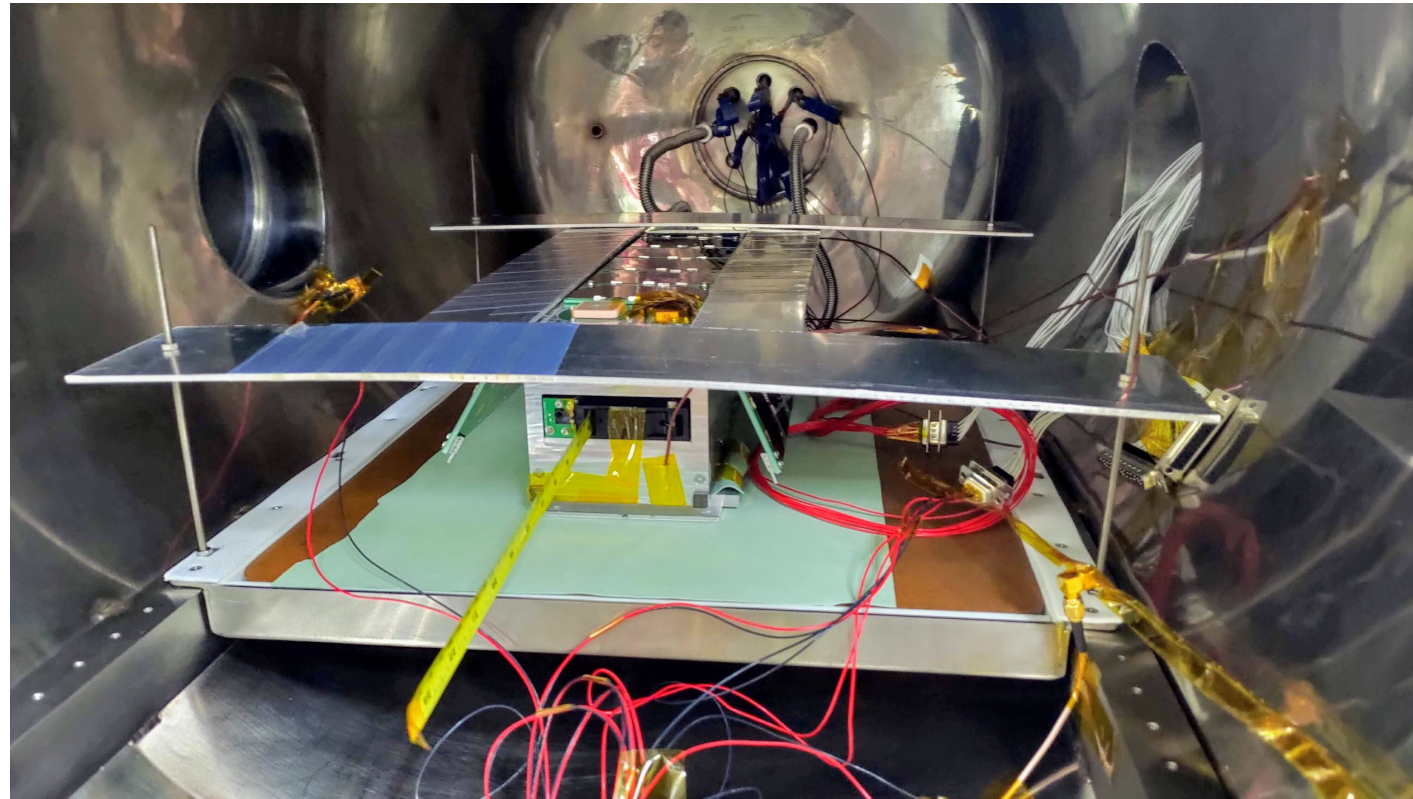
Vibration

End to End

- ==Shock / vibration== and ==thermal vacuum== tests as required by launch provider with factor of safety.

- ==Functional tests== for flight software, power generation, deployment, ==communications end to end==.

- Delivery deadline: 2020/11/27

Lesson Learned:
FM integration & test is most critical, but also most constrained in time.

Delivery & Integration with launch vehicle 2020/11/27

SpaceX Falcon 9 Launch 2021/01/24

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First flight data beacon received from SatNOGS (amateur radio network): T + 4 hours.
SatNOGS great resource for extending ground coverage.

IDEASSat Thermal Performance (°C, 2020/01/24 – 02/15)

Good thermal isolation of batteries from surrounding subsystems.

Improvements needed in deployable solar panel hinge mechanism and solar panel PCB fabrication.

Exposed solar panels show extreme temperatures. Body mounted panel hotter.

Good heat conduction away from UHF transceiver through chassis interface.

Core avionics stack running warmer than expected.

Battery Op Limit
Battery Tvac
Battery Predicted
Battery 2 On Orbit
Battery 1 On Orbit

PV Op Limit
PV Tvac
PV Predicted
PV2 On Orbit
PV1 On Orbit
PV0 On Orbit

UHF Op Limit
UHF Tvac
UHF Predicted
UHF On Orbit

EPS Op Limit
EPS Tvac
EPS Predicted
EPS On Orbit

CDH Op Limit
CDH Tvac
CDH Predicted
CDH On Orbit

-150   -100   -50   0   50   100   150   200

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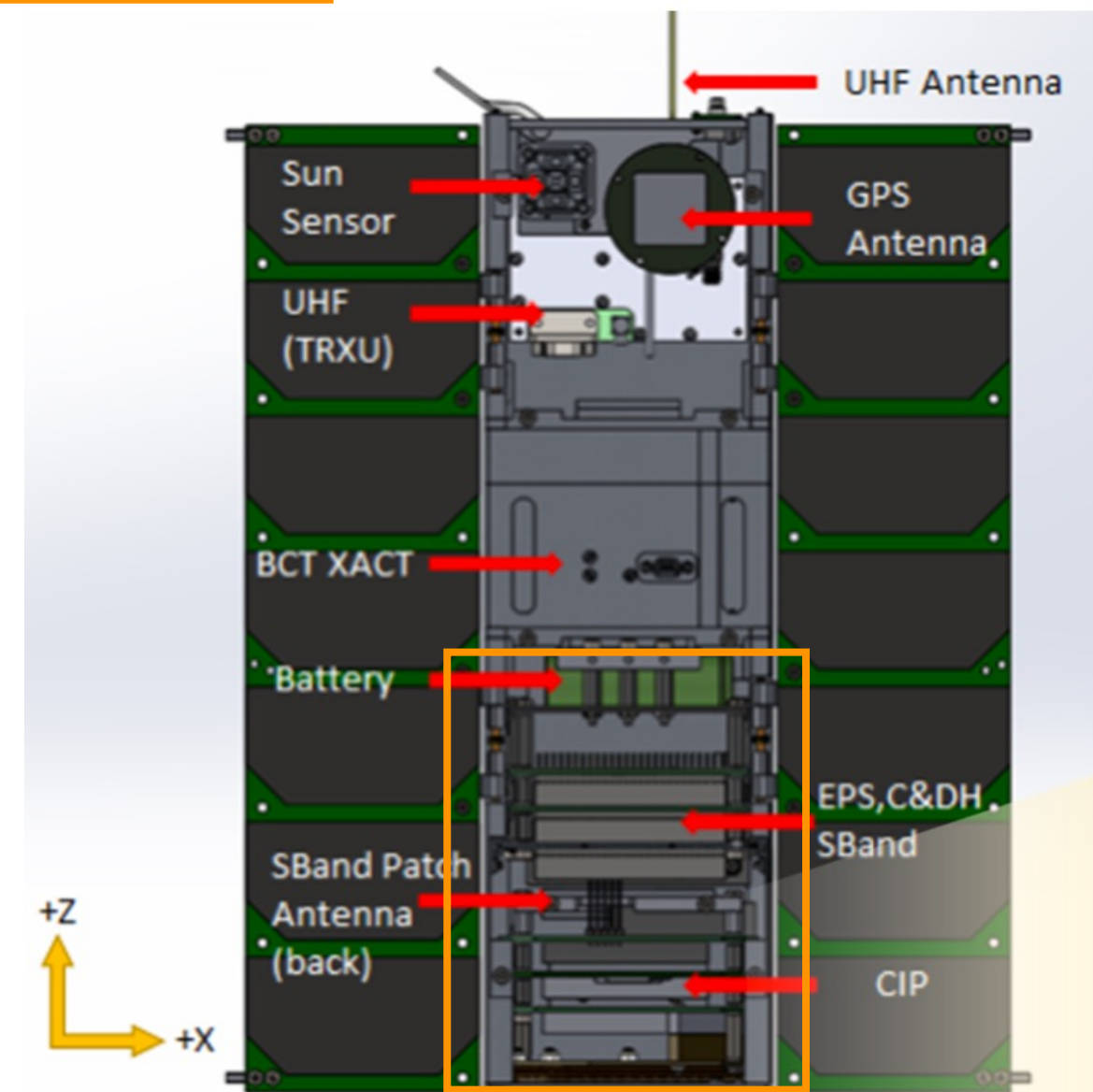
Post Launch State (1/24 – 2/15)
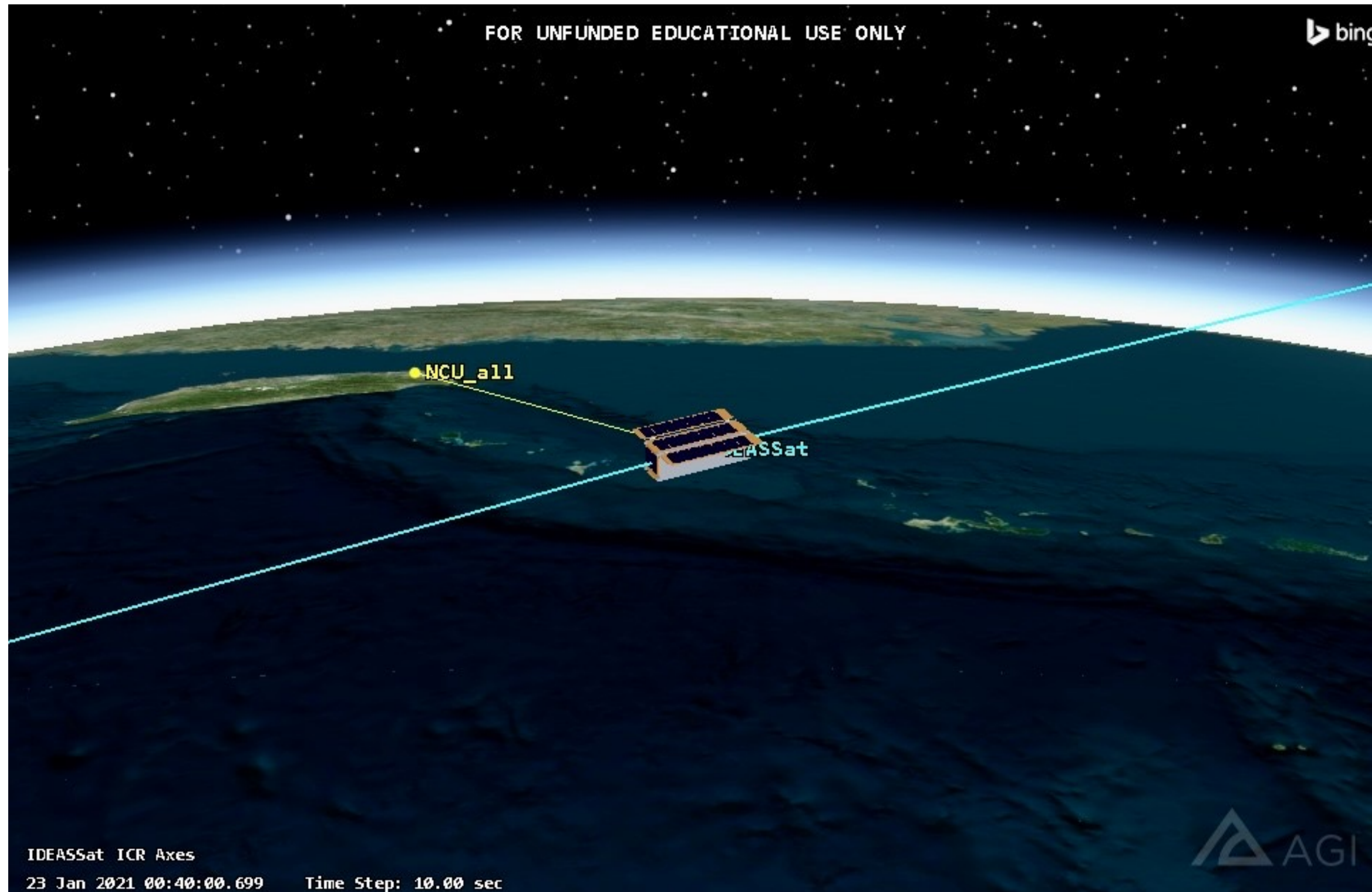
- Spacecraft in Safe mode pending commissioning (need to verify command uplink and pointing for Science mode).

- Very healthy battery SOC > 90%.

- ADCS maintaining Sun pointing mode. GPS functional. Star tracker solution available. Constantly returning flight data (inc. GPS).

- Anomalies encountered:

  - Single Event Upset

  - Partial solar panel deployment.

  - **UHF COMM Blackout: 2/15 – 4/2**

Recovery (4/2)
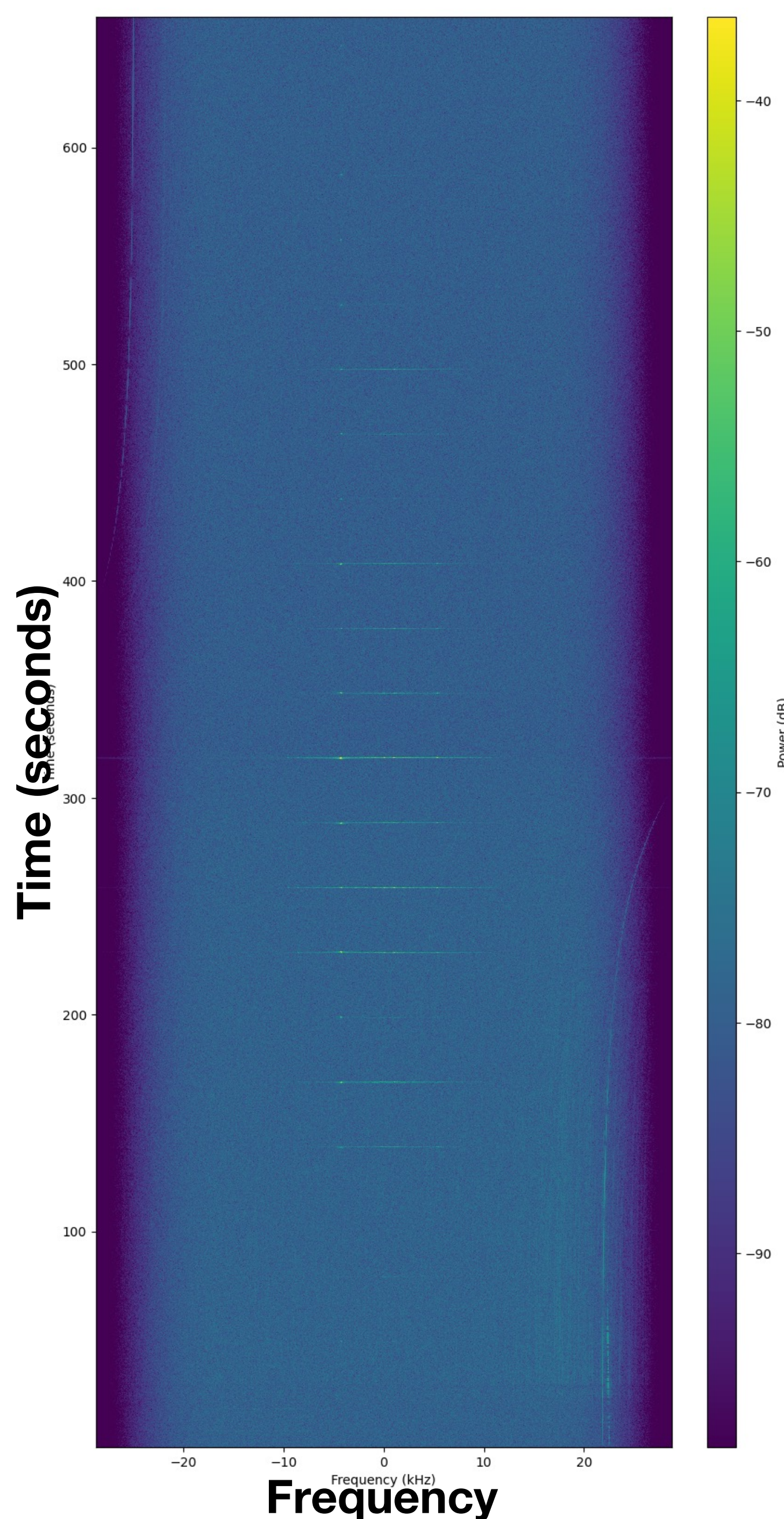
- Spacecraft began beaconing again on 4/2.

- Contact reestablished with NCU ground station on 4/3. Successfully uplinked commands to replay saved flight data.

- ==Initial SOC value around 85% was lower then ever detected previously suggesting possible deep discharge event.==

- ==Reset of counters in flight data indicates spacecraft power cycle occurred. Reboot not indicated in flight data, suggesting that reset was not triggered by FSW.==
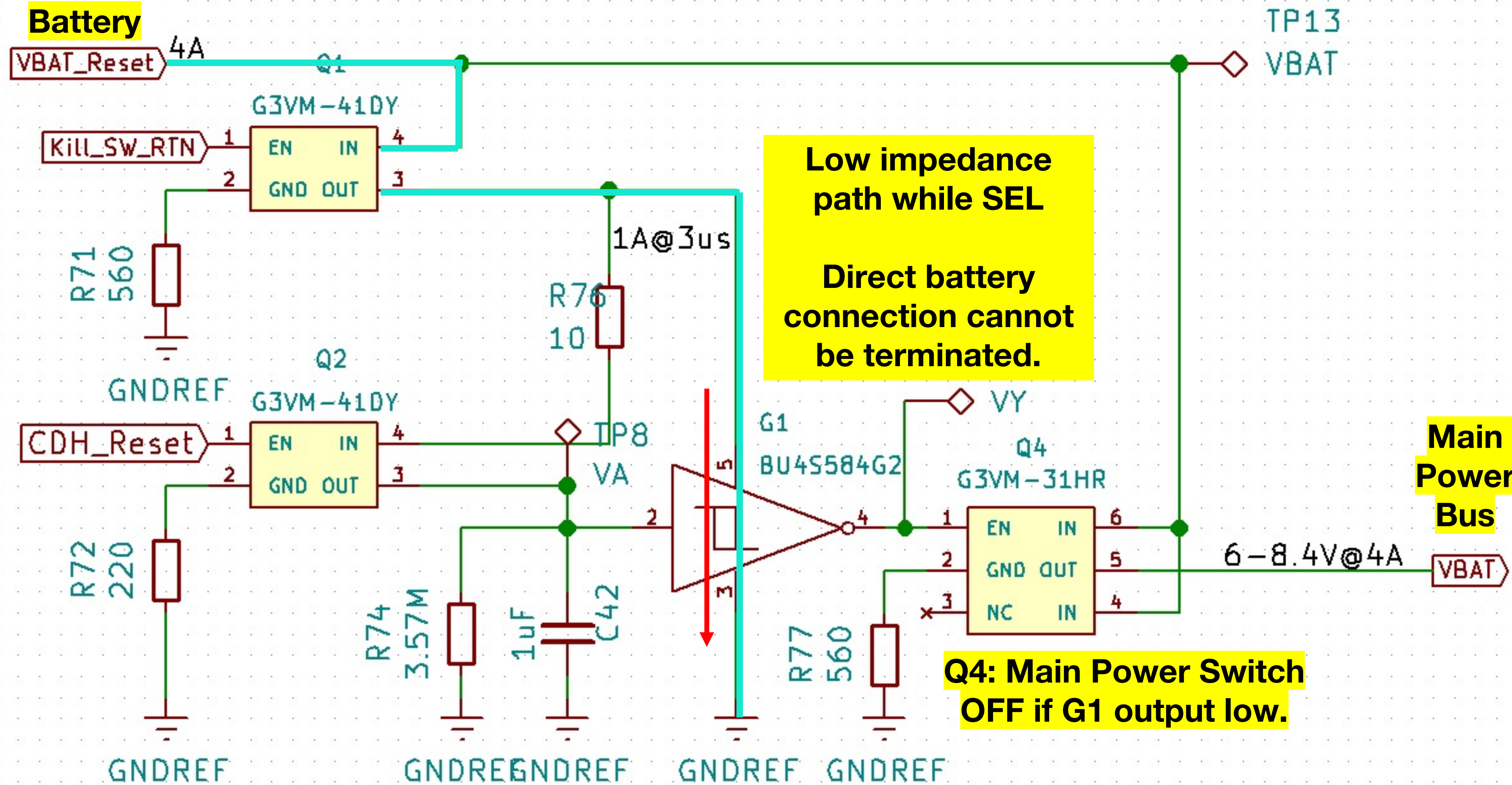
- ==Beacon packet numbering shows flight data was not logged during blackout period, likely due to C&DH not being powered on.==

- Beaconing stopped again on 4/5.

  - Continuing to track and preparing for further flight data downlink.

IDEASSat EPS Main Power Bus Circuit

- G1 CMOS IC at risk of single event latchup (SEL) from energetic ion strike, which will power down entire spacecraft until cleared.

- SEL cannot be cleared until sufficient discharge of battery.

- EPS redesigned to include overcurrent protection for SEL recovery.

Low impedance path while SEL

Direct battery connection cannot be terminated.

Q4: Main Power Switch OFF if G1 output low.

Lesson Learned:
Total dose affects overall lifetime, but Single Event Effects are a matter of probability.

Conclusions

Technological Readiness Level (TRL)
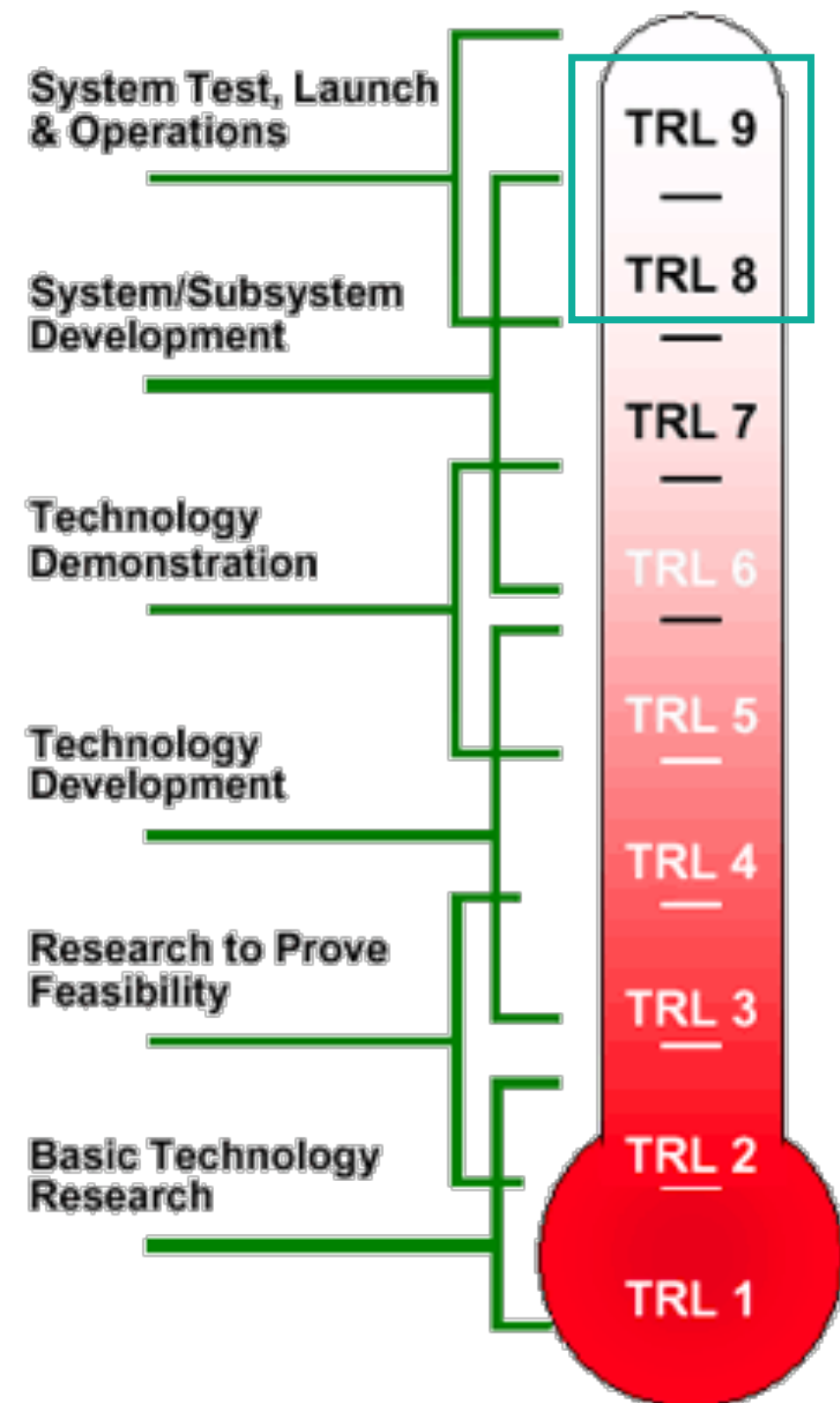
- **Design:** Spacecraft functions were capable of ensuring excellent power, link, and thermal margins, as well as 3-axis attitude control, two way communication, and return of flight data on orbit. <mark>Modifications to self-developed EPS necessary according to results of fault analysis.</mark>

- **Workmanship**: Spacecraft survived launch environment and successfully activated on orbit. <mark>Testing plans for future spacecraft need to be capable of detecting anomalies that will not appear until extended operation on orbit</mark>.

NCU self-developed avionics (on-board computer, electrical power subsystem, structure) are now flight tested and TRL 8 – 9.

Future work needed to improve robustness of self-developed avionics to allow for reliable operation over at least 1 year.