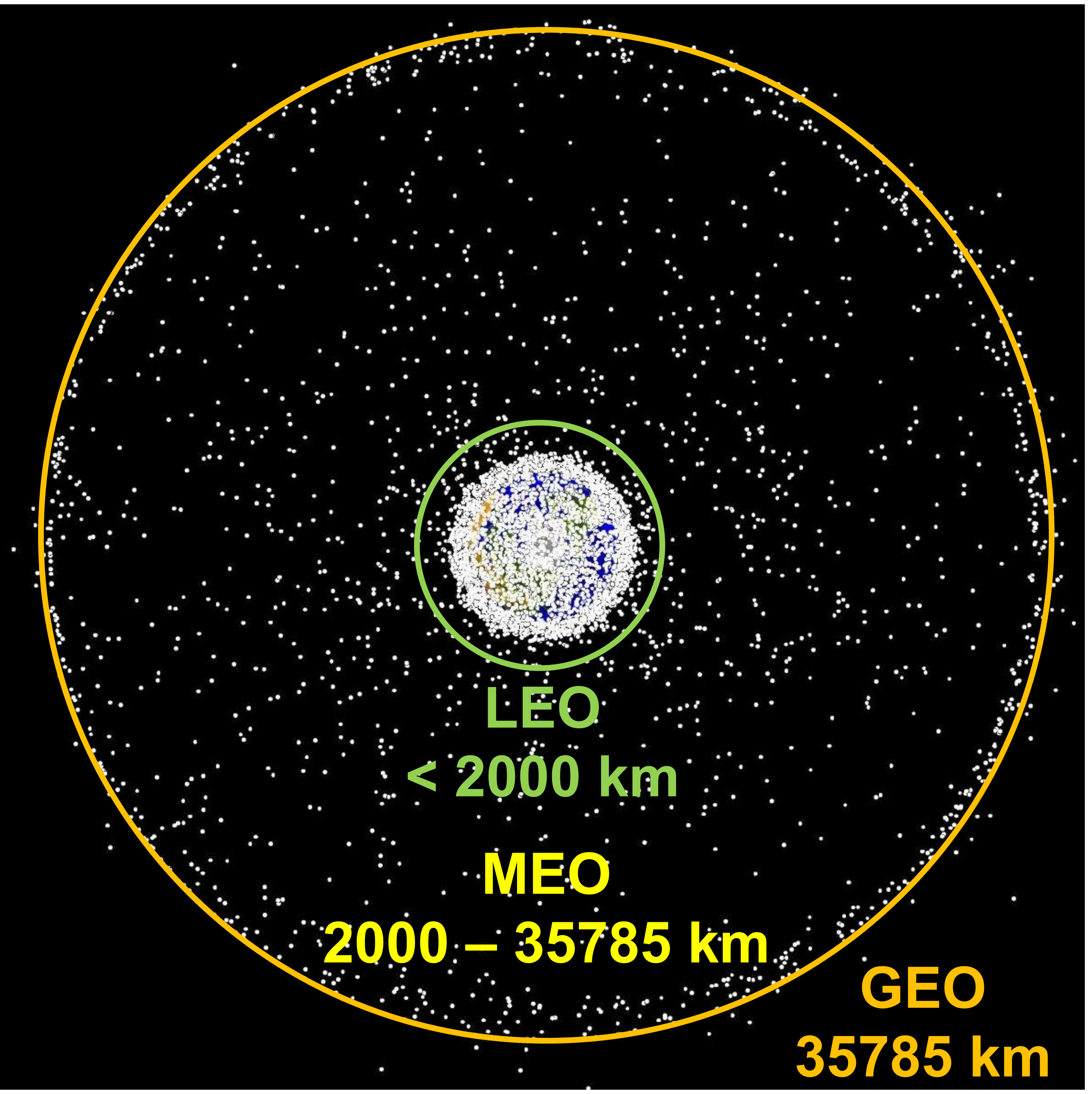
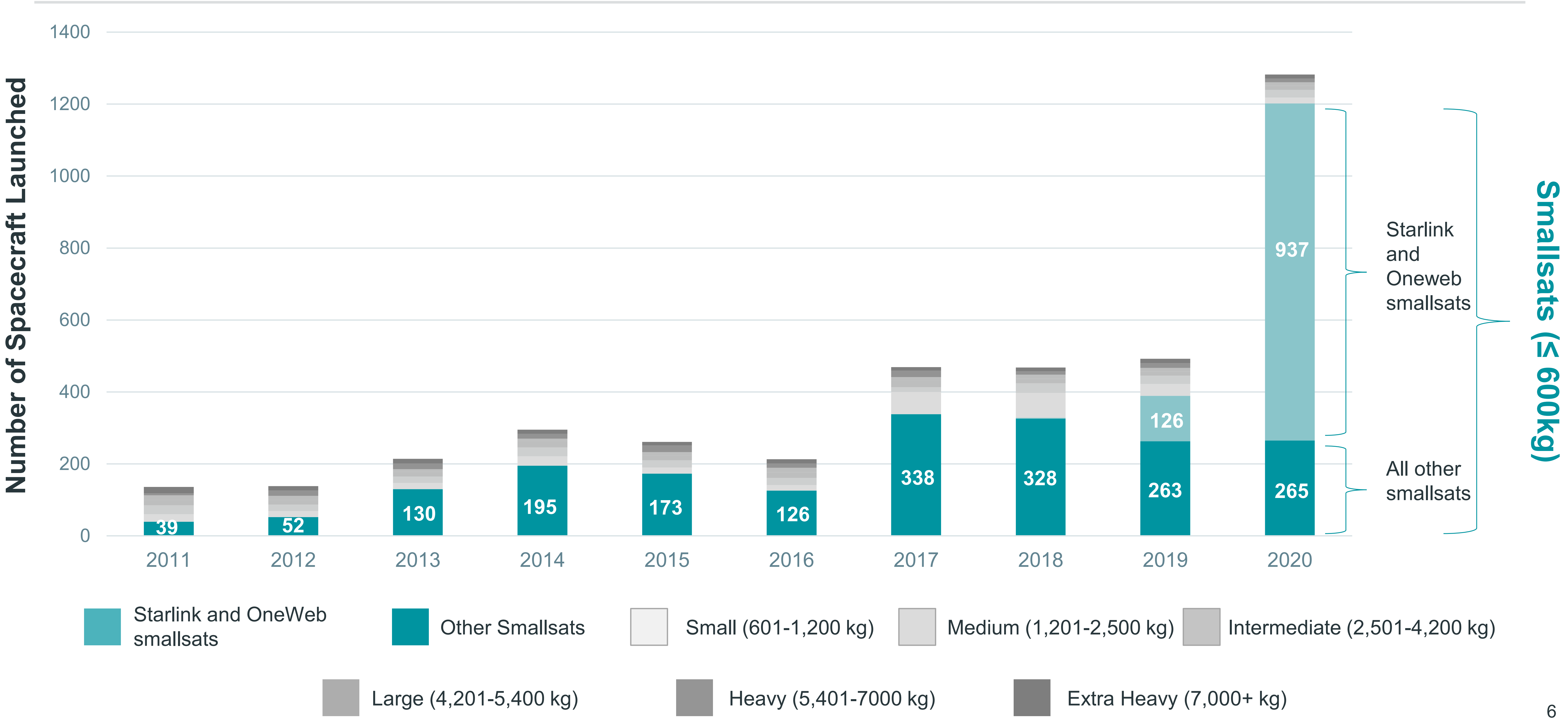
Development and Operational Experience from IDEASSat and Lessons Learned

國立中央大學 太空科學與工程學系
張起維 教授



Source: Bryce Tech



6

Active Satellites: 4084 (2021/04/30)

Increasing utilization of space using small satellites.

Satellite Sizes (US Federal Aviation Administration)

Extra Heavy
> 7000 kg

Heavy
5400 - 7000 kg

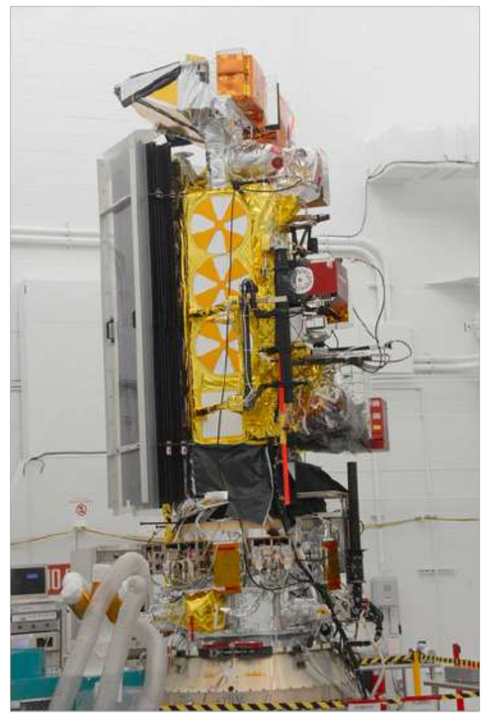
Large
4200 - 5400 kg

小型衛星
Smallsats

Himawari 8, 3500 kg

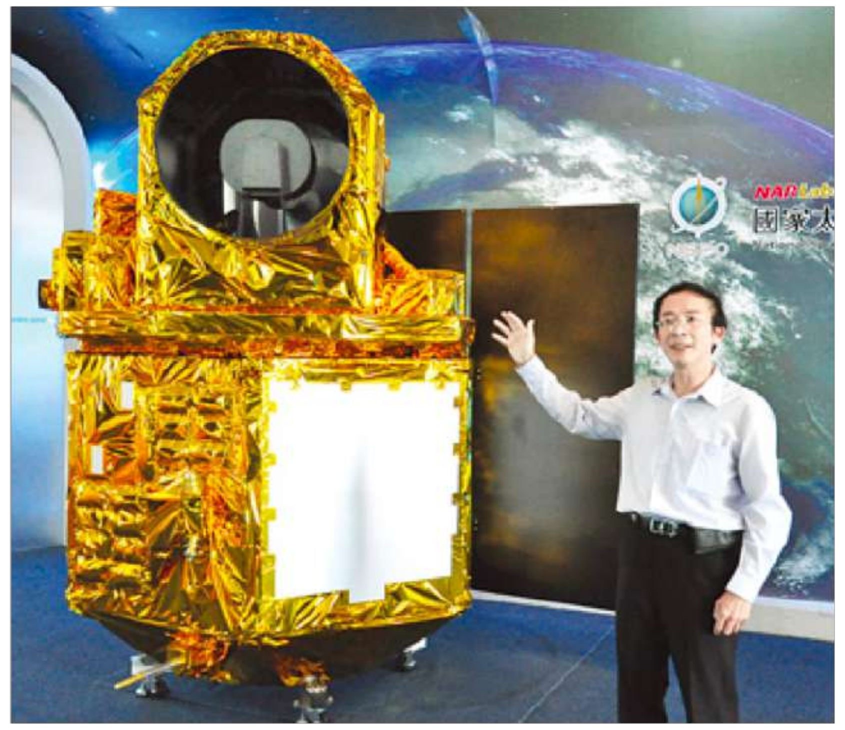
Intermediate satellite
2500 - 4200 kg

NOAA-19, 1440 kg



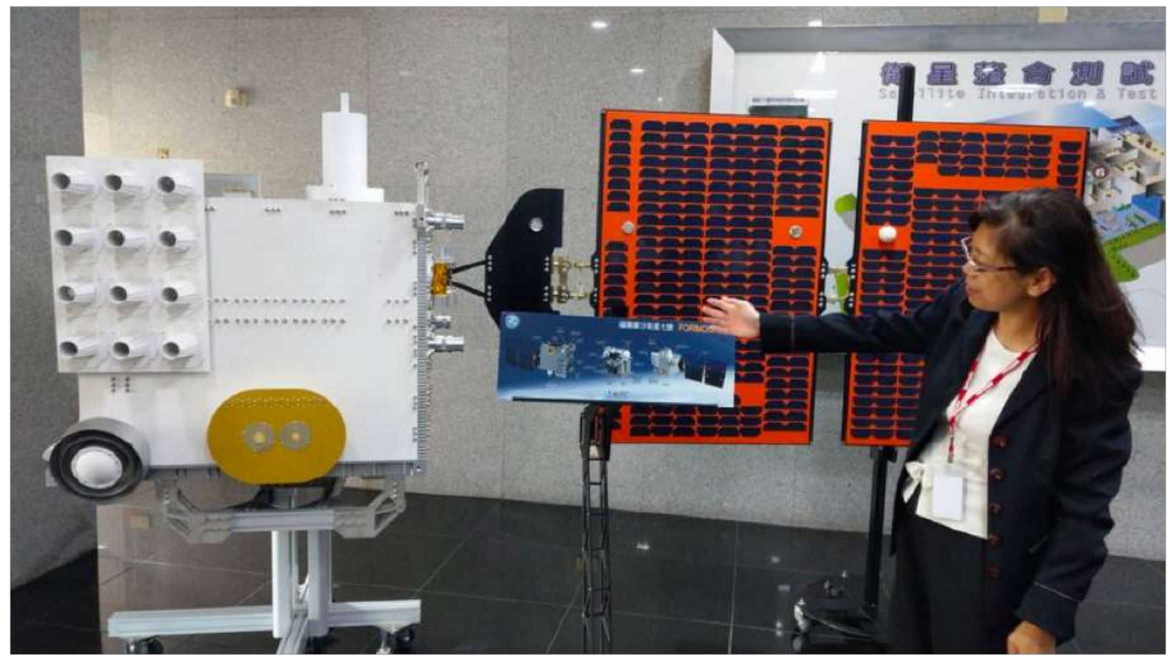
Medium satellite
1200 - 2500 kg

FORMOSAT-2, 768 kg



Small satellite
600 - 1200 kg

FORMOSAT-7, 300 kg

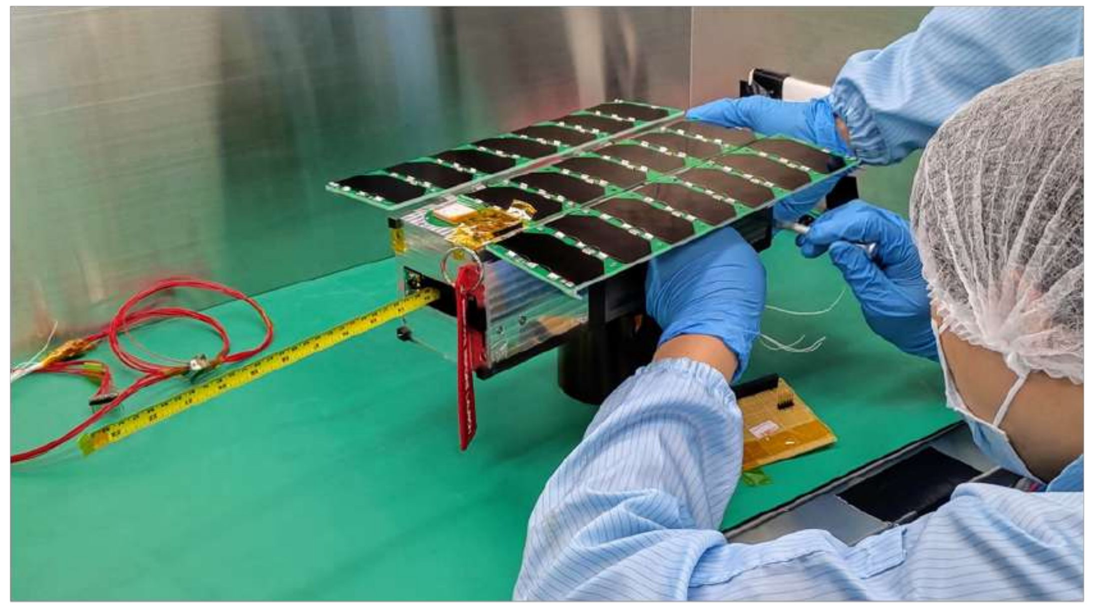


Minisatellite
200 - 600 kg

FORMOSAT-3, 62 kg

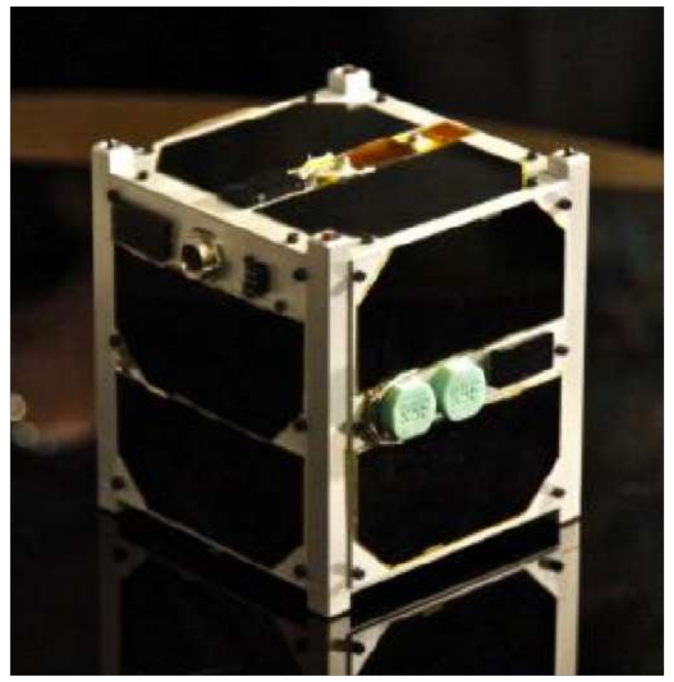
Microsatellite
10 - 200 kg

IDEASSat, 4.5 kg



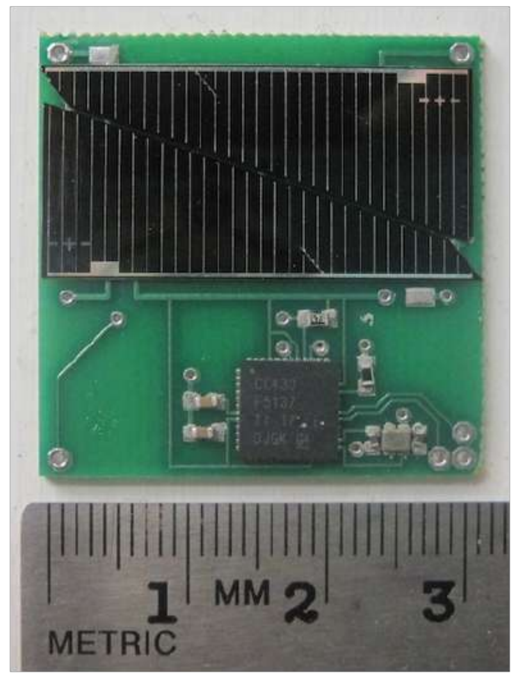
Nanosatellite
1 - 10 kg

ESTCube, 1.05 kg



Picosatellite
0.1 - 1 kg

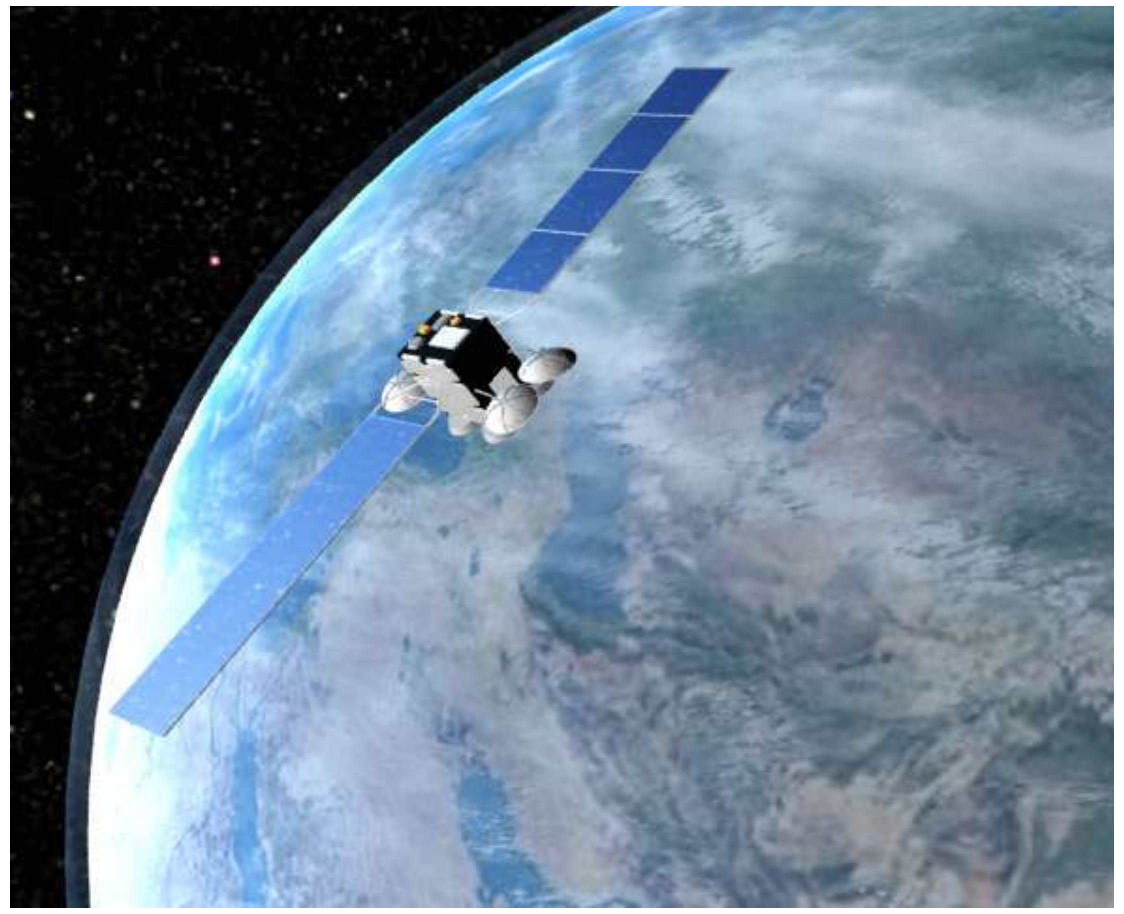
Sprite, 10 g

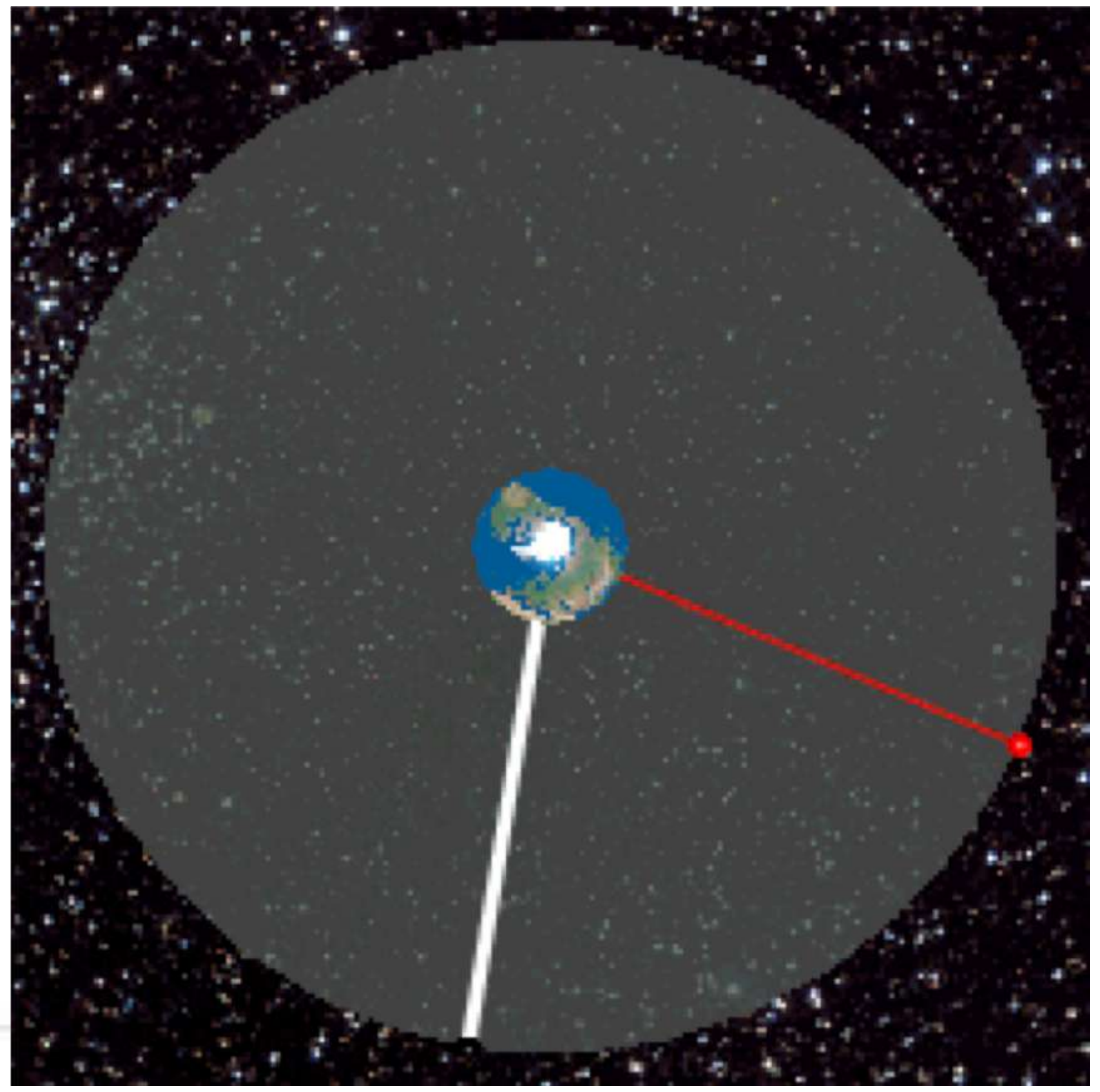


Femtosatellite
< 0.1 kg

Geostationary Satellite: ST-2 (中新2號)

ST-2 K1 Band	EIRP (dBW, min.)	G/T (dB/K, min.)
台北	56.3	8.7
高雄	55.6	9.0
上海	51.5	3.7
福州	55.1	7.6
香港	51.3	3.7
金邊	50.6	1.7
胡志明市	50.3	3.1
馬尼拉	51.0	3.3
雅加達	50.3	3.9
新加坡	55.6	7.7
Peak	56.4	9.4





Mass: 5090 kg
Lifetime: 15 years
Orbit: 35785 km
Geostationary

中華電信：https://www.cht.com.tw/home/campaign/gxc/c6-en/satellite-strs/index.html

Standardization

SEA CONTAINER SPECIFICATIONS

DRY CARGO CONTAINERS

• DIMENSIONS

Type	Container Weight Gross (kg)	Tare (kg)	Net (kg)	Interior Measurement Length (m)	Width (m)	Height (m)	Capacity (m³)	Door Open Width (m)	Height (m)
20 ft	24,000	2,370	21,630	5.898	2.352	2.394	33.20	2.343	2.280
40 ft	30,480	4,000	26,480	12.031	2.352	2.394	67.74	2.343	2.280

• CHARACTERISTICS

Manufactured from either Aluminium or steel, they are suitable for most types of cargo / general cargo. Aluminium containers have a slightly larger payload than steel, and steel containers have a slightly larger internal cube

REFRIGERATED CONTAINERS

• DIMENSIONS

Type	Container Weight Gross (kg)	Tare (kg)	Net (kg)	Interior Measurement Length (m)	Width (m)	Height (m)	Capacity (m³)	Door Open Width (m)	Height (m)
20 ft	24,000	3,050	20,950	5.449	2.290	2.244	26.70	2.276	2.261
40 ft	30,480	4,520	25,960	11.690	2.250	2.247	57.10	2.280	2.205

• CHARACTERISTICS

Recommended for delicate cargo. Bottom-air delivery system ensures refrigerated cargo reaches its destination in optimum condition.

OPEN TOP CONTAINERS

• DIMENSIONS

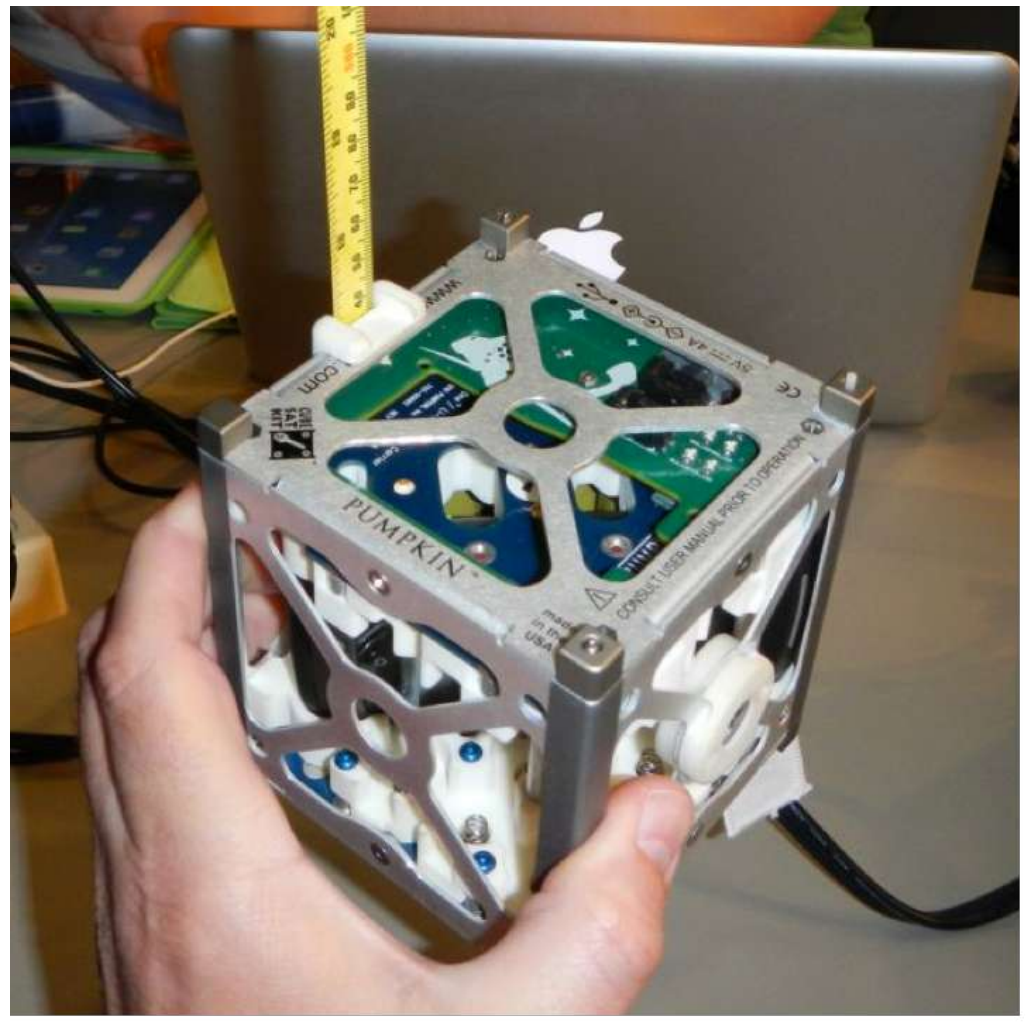
Type	Container Weight Gross (kg)	Tare (kg)	Net (kg)	Interior Measurement Length (m)	Width (m)	Height (m)	Capacity (m³)	Door Open Width (m)	Height (m)
20 ft	24,000	2,580	21,420	5.629	2.212	2.311	32.00	2.330	2.263
40 ft	30,480	4,290	26,190	11.763	2.212	2.311	65.40	2.330	2.263

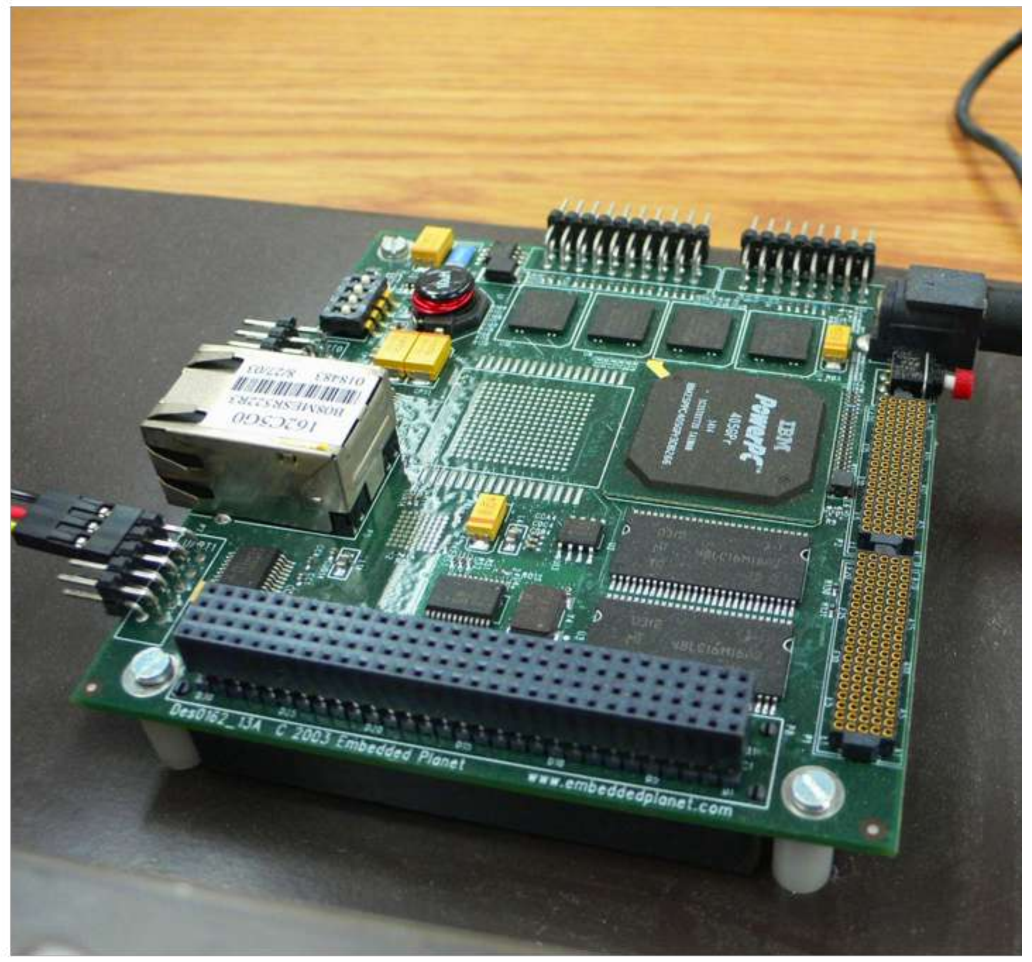
• CHARACTERISTICS

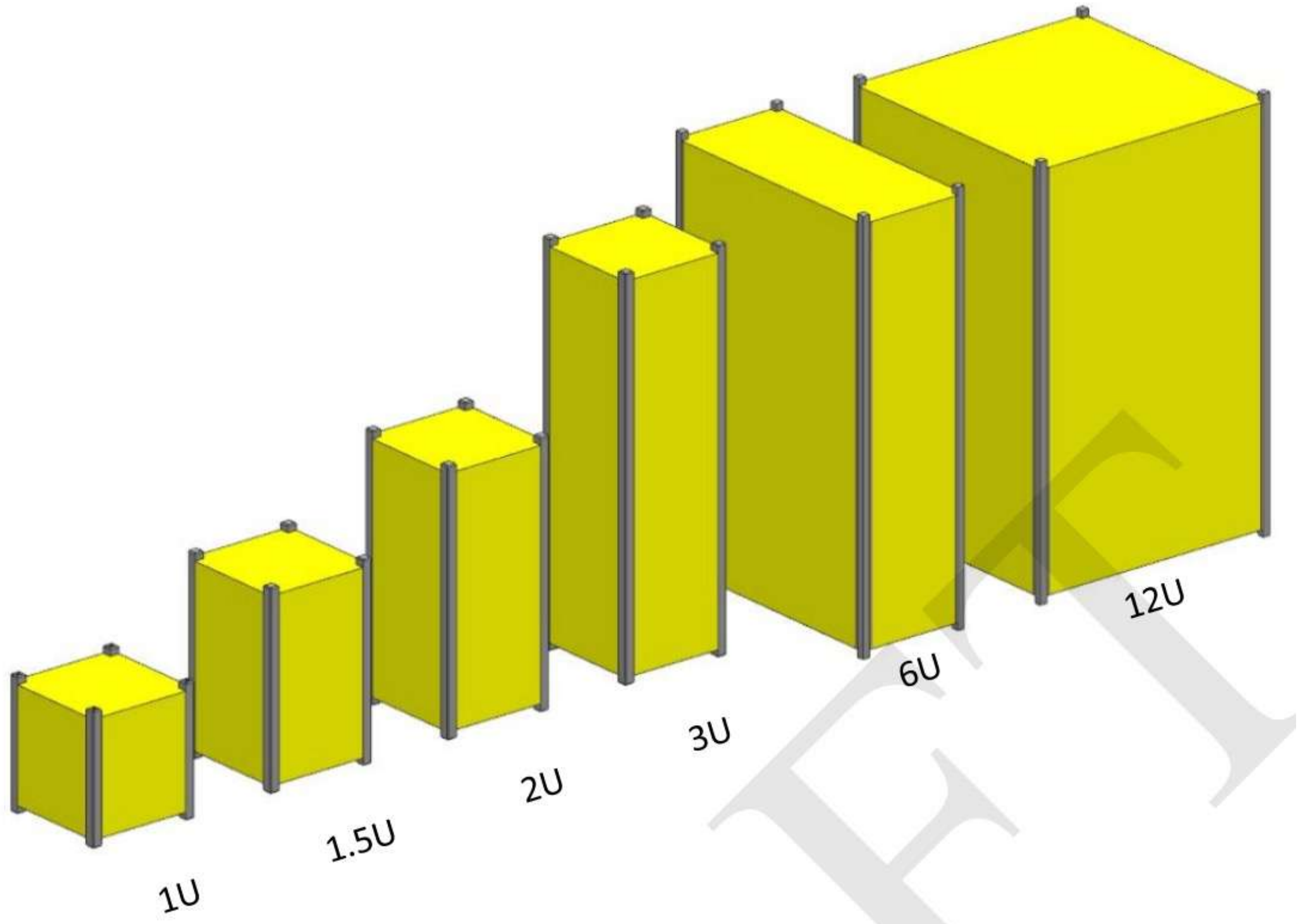
Allowing cargo to be loaded from the top, open top containers are particularly suitable for bulky cargo such as machinery. They are fitted with a PVC tarpaulin cover and attachable bows with cable sealing devices. The container doors can be removed to make the stuffing of cargo more convenient. Manufactured from steel

Significant reductions in time and cost of shipping through use of standardized containers.

CubeSats（立方衛星）







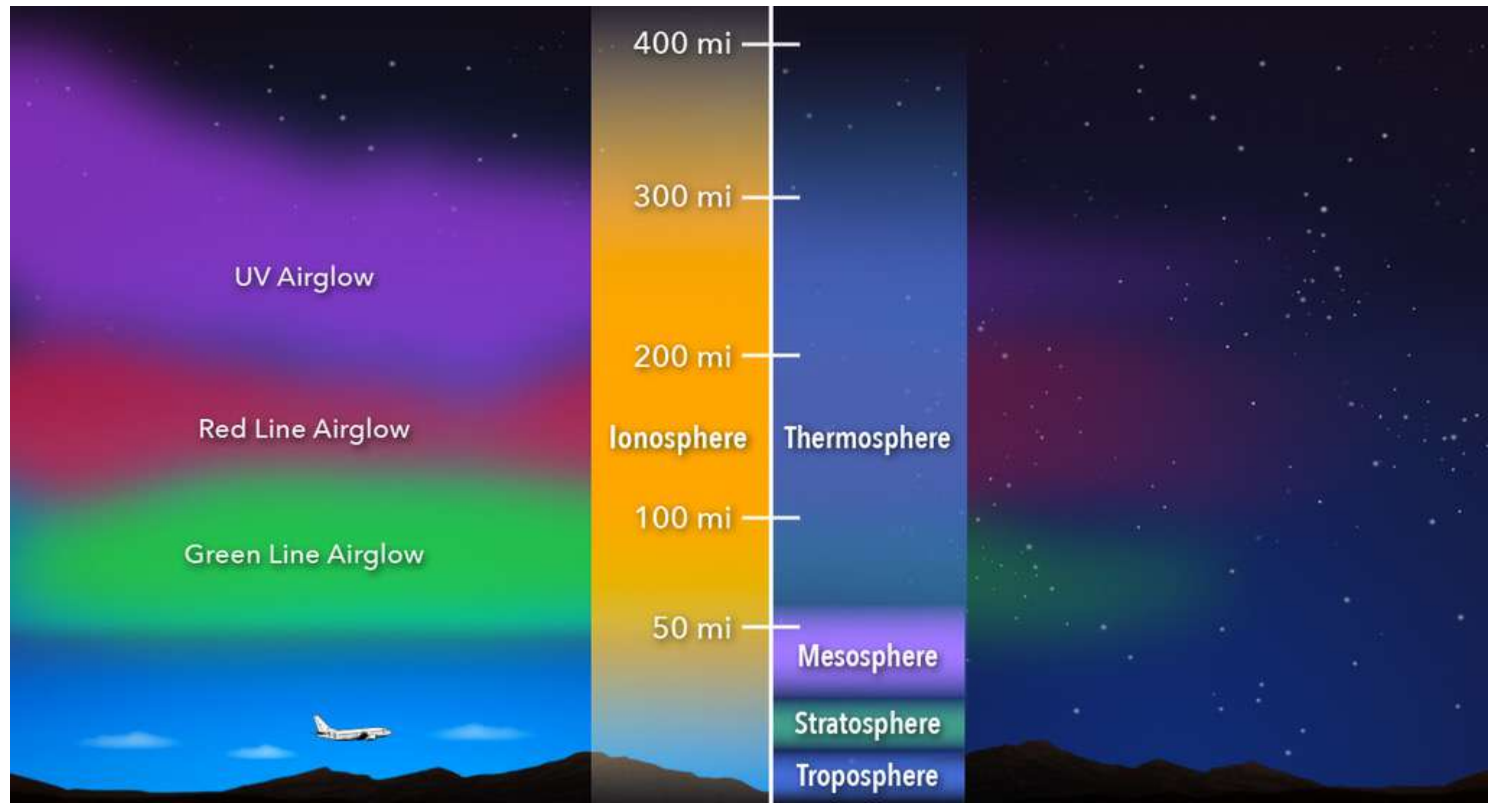
- Proposed in 1999 by Bob Twiggs (Stanford) and Jordi Puig-Suari (CalPoly) for use in science and engineering education.
- Commercial grade hardware in PC-104 form factor.
- 1U = 10 x 10 x 10 cm
- Users: Universities, Commercial, Government.
- Fast development time. CubeSat Design Specification 由CalPoly (加州理工州立大學)定義、維護：https://www.cubesat.org/cubesatinfo

Trends: COTS Spacecraft, Complete Solution

Customer | **Spacecraft Service Provider** | **Customer**

Payload Mission Concept → Spacecraft Design Fabrication → Integration & Test → Launch Operations → Data

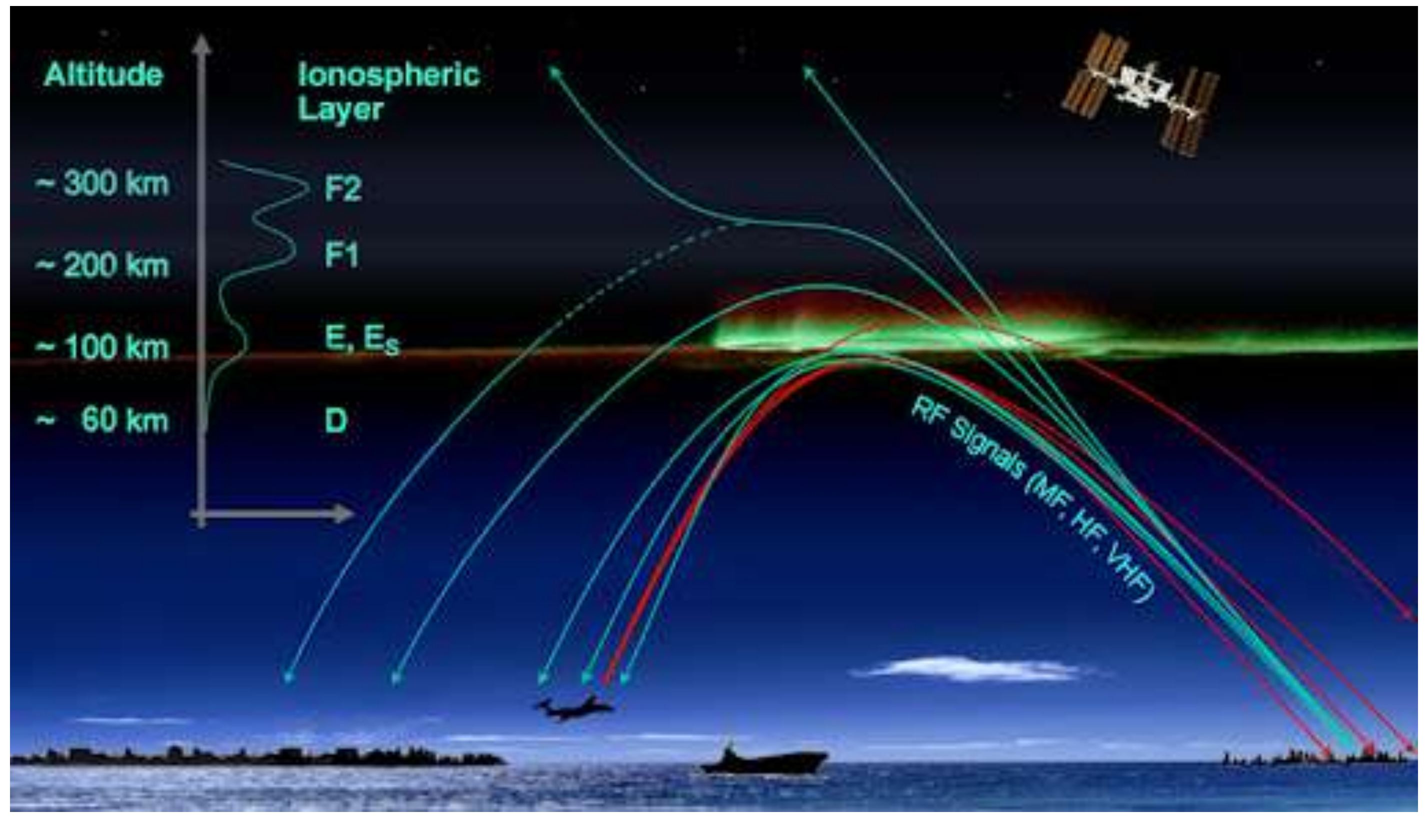
LEO Natural Space Environment Hazards

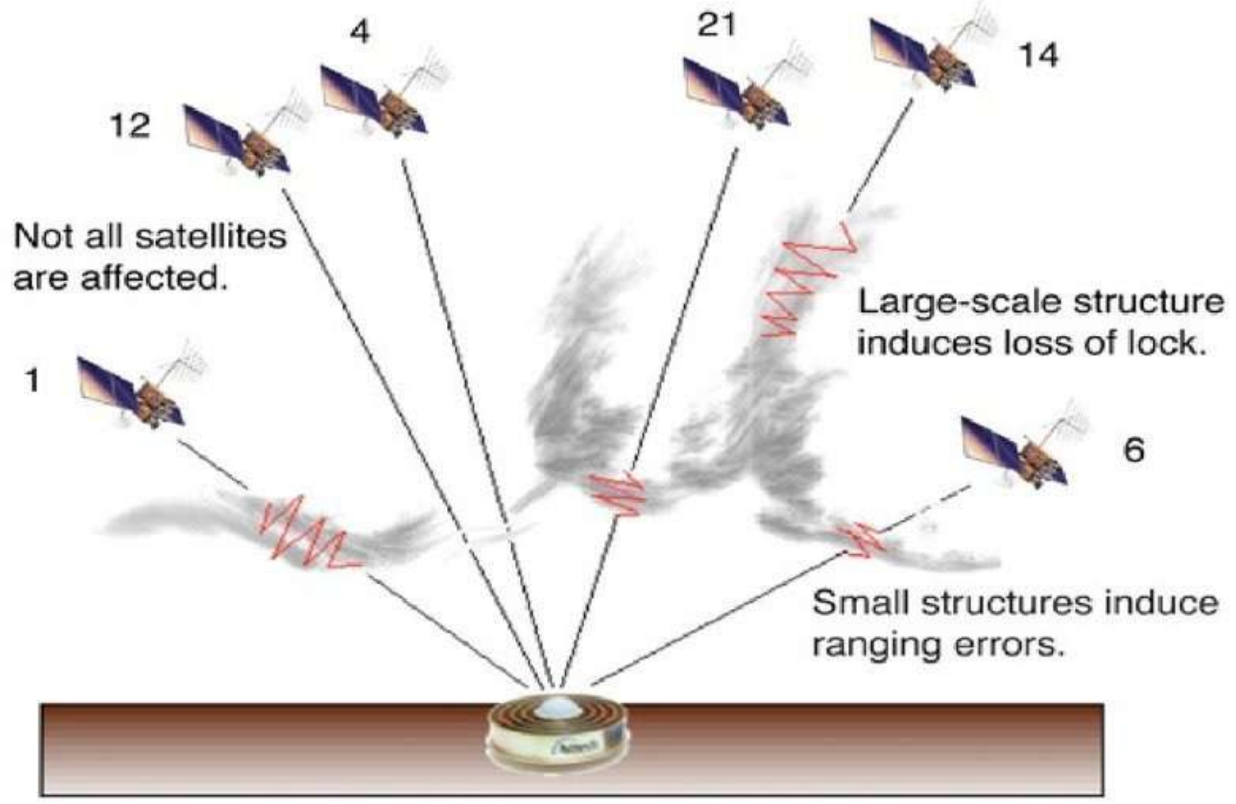


THERMOSPHERE 熱氣層

Orbit perturbations and de-orbit from upper atmospheric drag.

Corrosion of spacecraft structure from atomic oxygen.



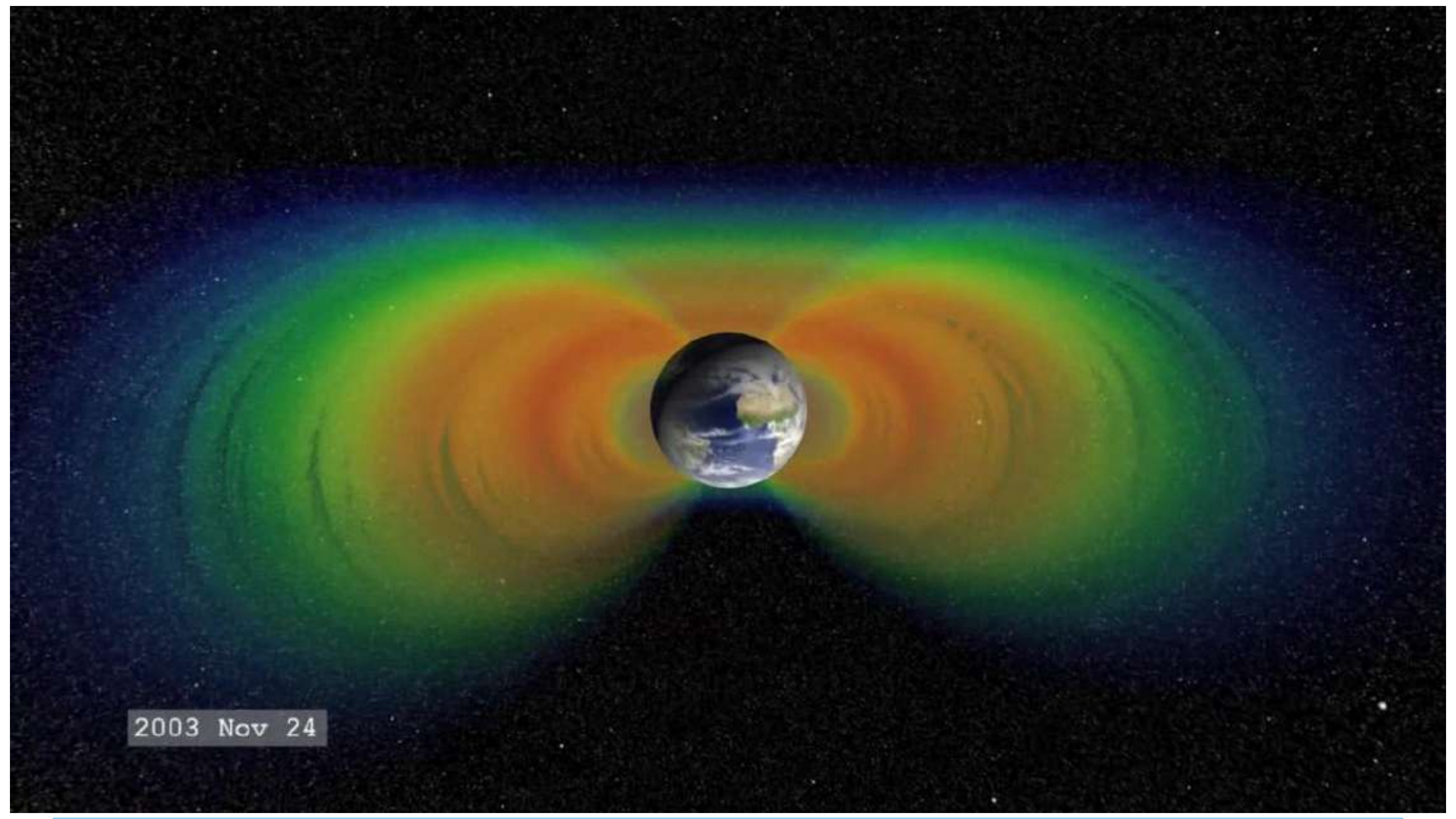


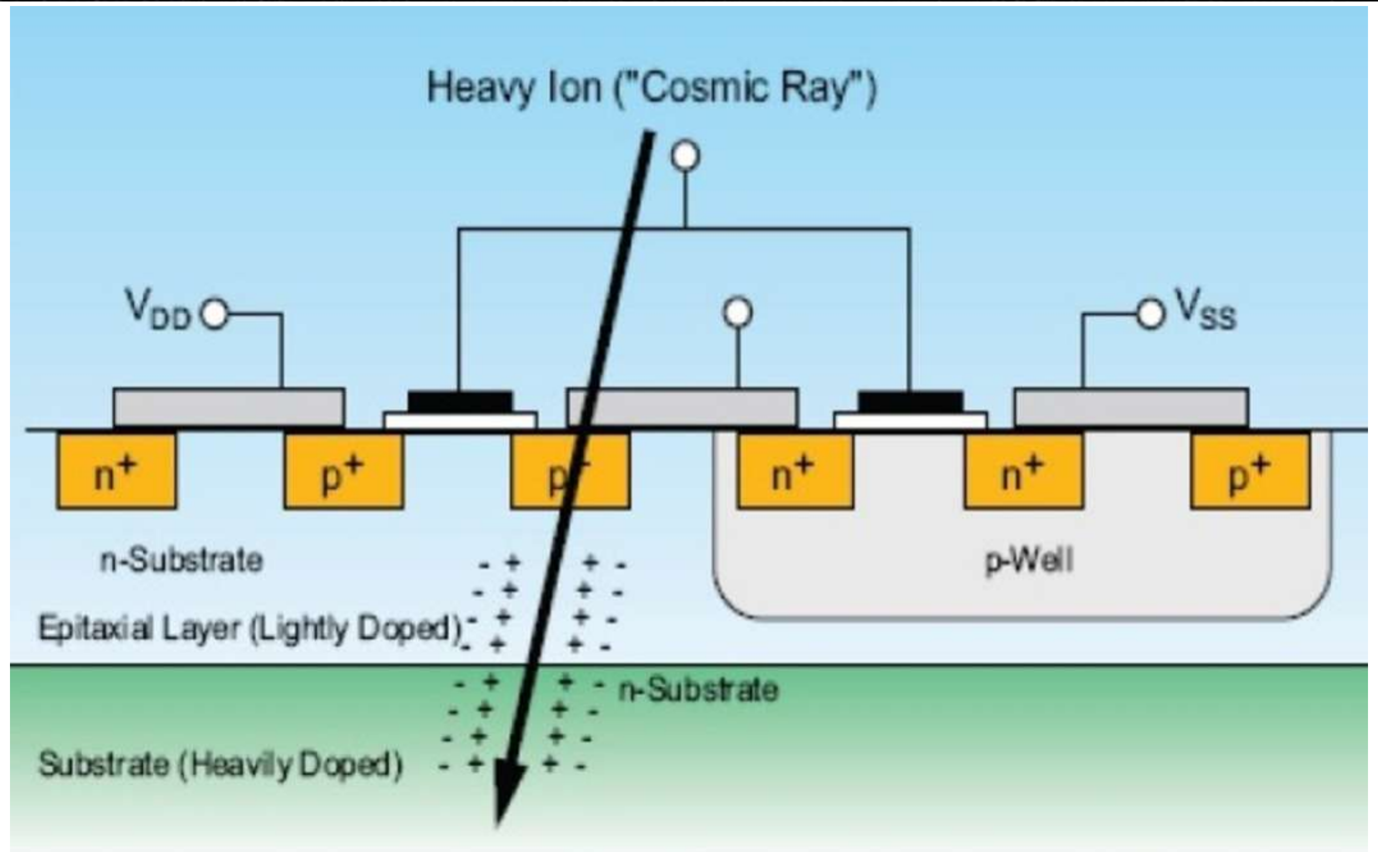
IONOSPHERE 電離層

Disruption of satellite communications and navigation signals.

Introduction of GPS range error.

Spacecraft surface charging.





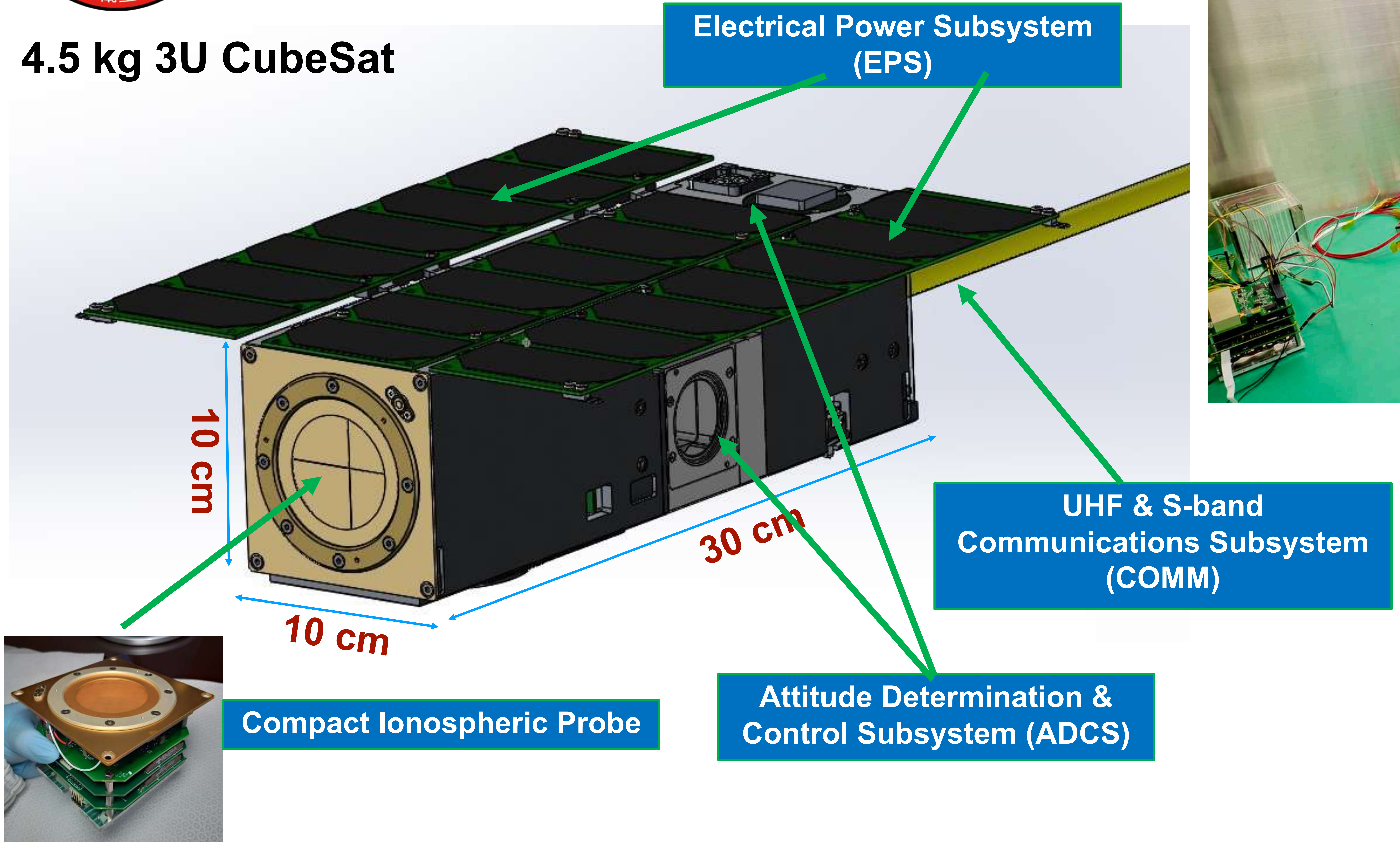
IONIZING RADIATION 游離輻射

Total Ionizing Dose

Single Event Effects

IDEASSat / INSPIRESat-2

4.5 kg 3U CubeSat



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

Flight Heritage 飛行履歷

Technological Readiness Level 技術完備等級 (TRL)

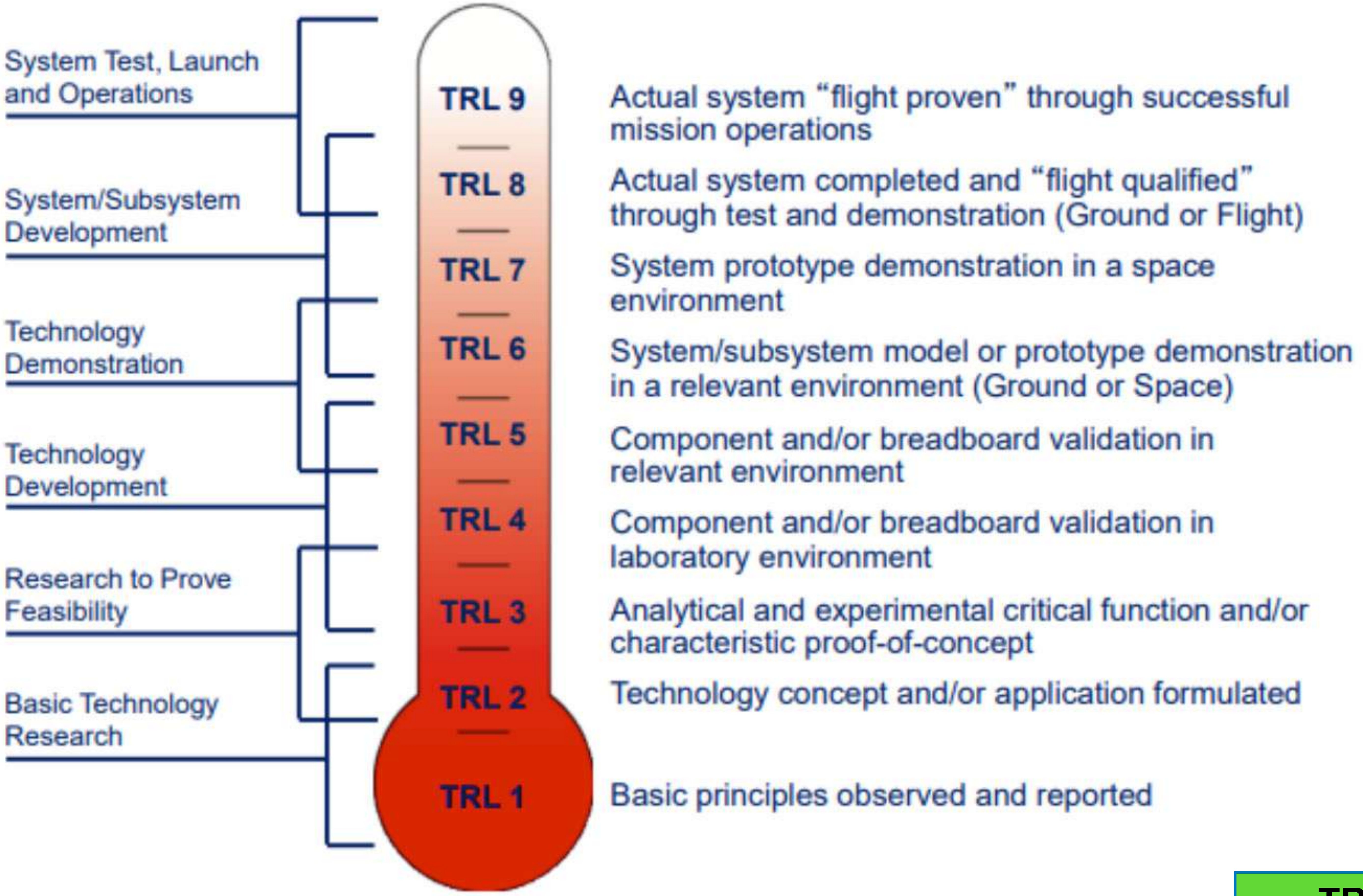


Figure 1. NASA Technology Readiness Level chart (©NASA)

已通過實際任務證明系統可實用。

實際系統完成並通過測試和演練。

完成系統原型在太空環境驗證。

完成系統/次系統飛行體或原型在地面或太空作業環境驗證。

元件或麵包板在作業環境驗證完成。

完成元件或組成在實驗室環境驗證。

已分析及實驗關鍵功能和 / 或概念的定性證明。

已制定技術概念和 / 或實際應用。

已觀察到並報導基本原理。

TRL 9 產品廣受航太界信賴並反映在售價上！

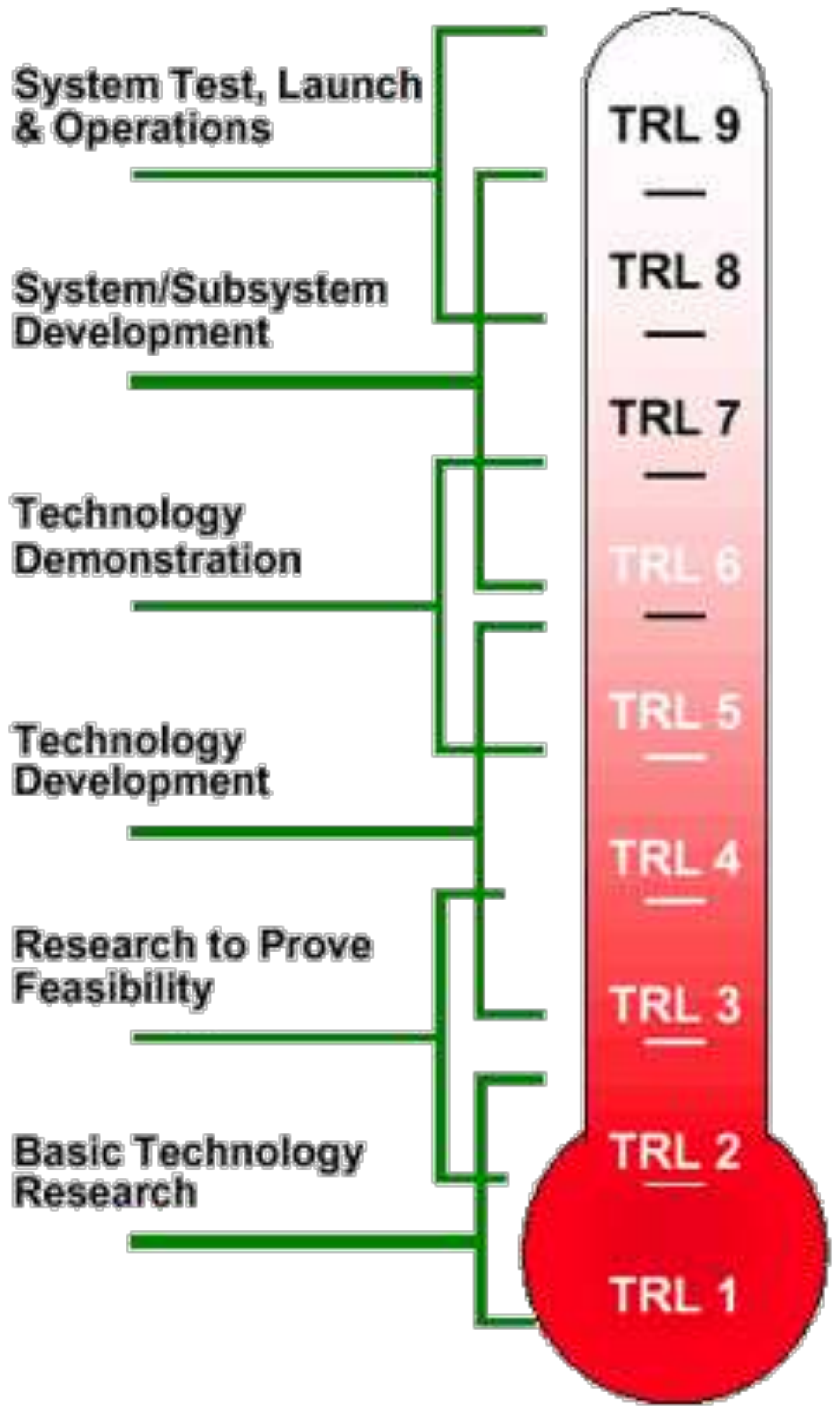
IDEASSat System Overview

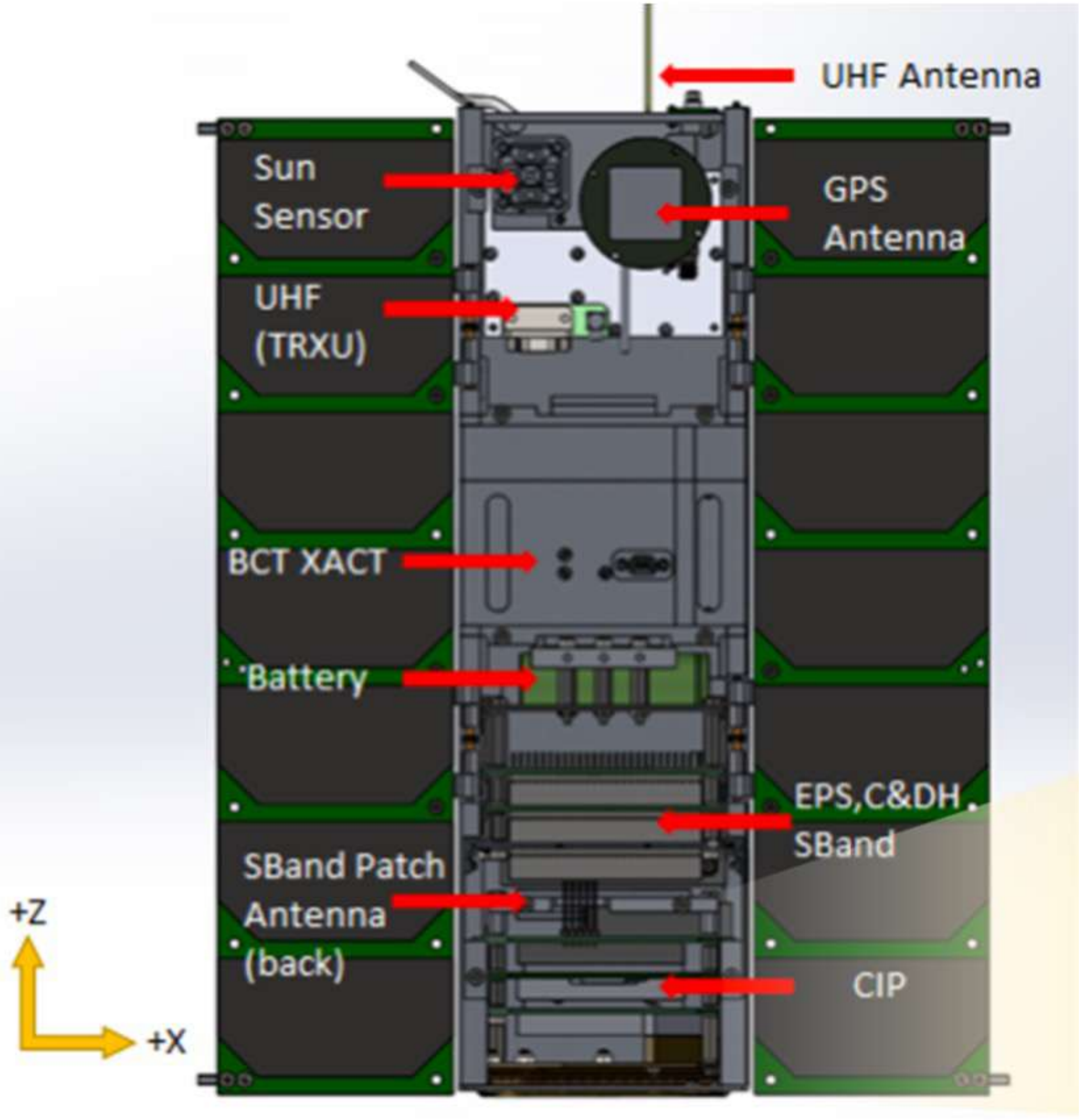
Subsystem	Solution	TRL
ADCS	Blue Canyon Technologies XACT with GPS	9
COMM (UHF transceiver)	SpaceQuest TRX-U	9
COMM (UHF Antenna)	Deployable monopole antenna	9
COMM (S-band transmitter)	CPUT STX-01-0017	9
EPS (Battery & Control PCBs)	NCU EPS	8
	18650 Li-ion batteries	9
EPS (Solar Cells)	AzurSpace TJ 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

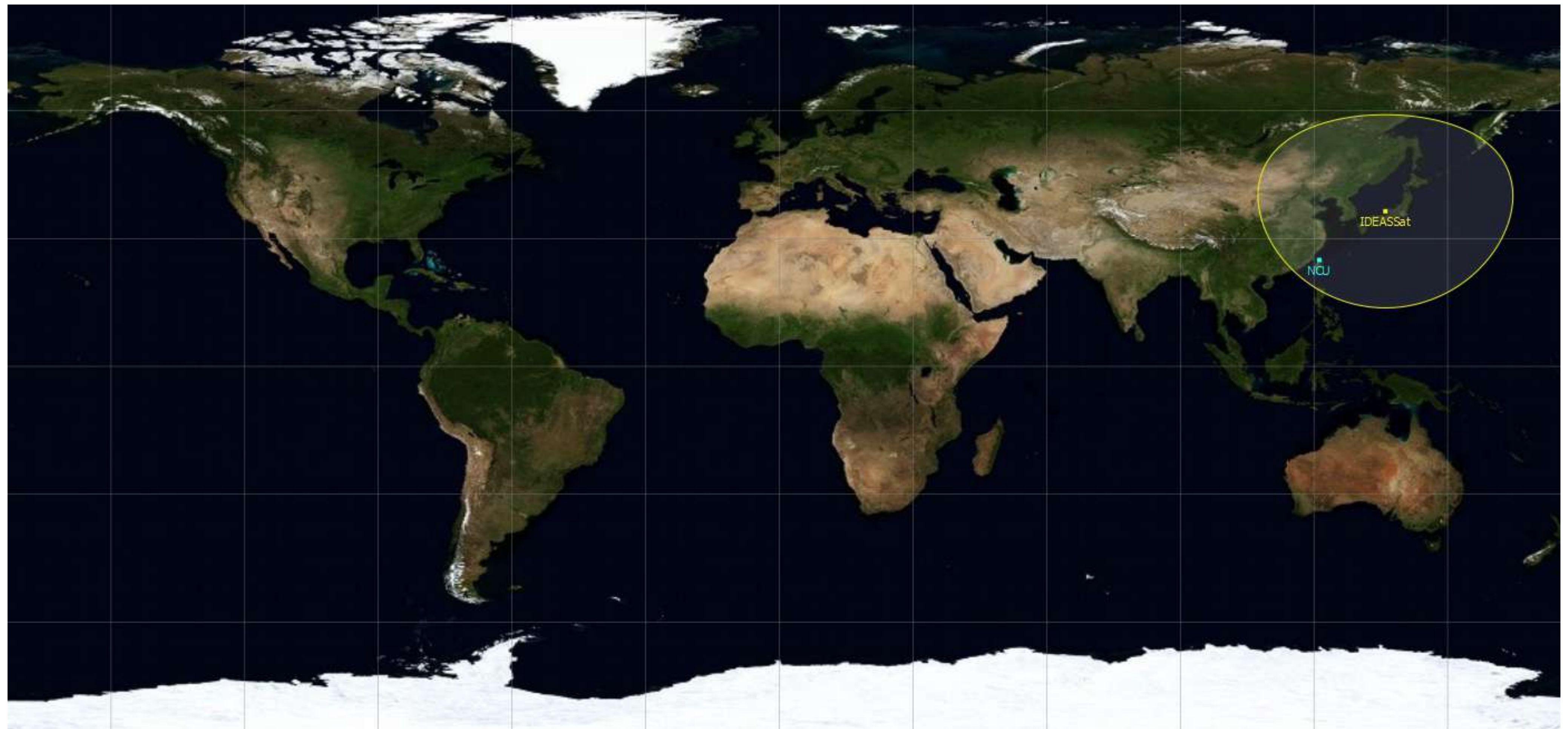
Flight Heritage Commercial Off the Shelf (COTS)

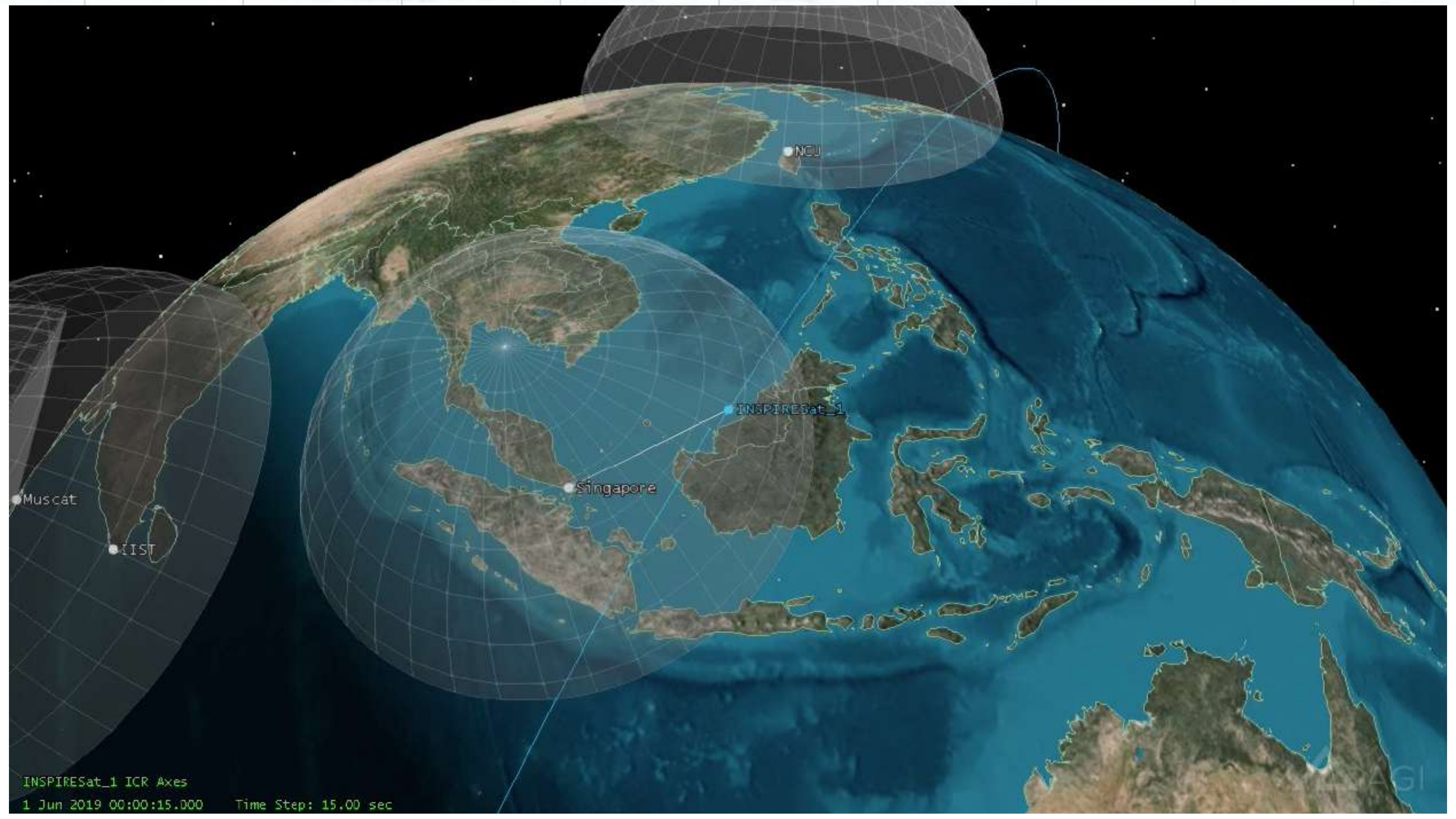
Technological Readiness Level (TRL)

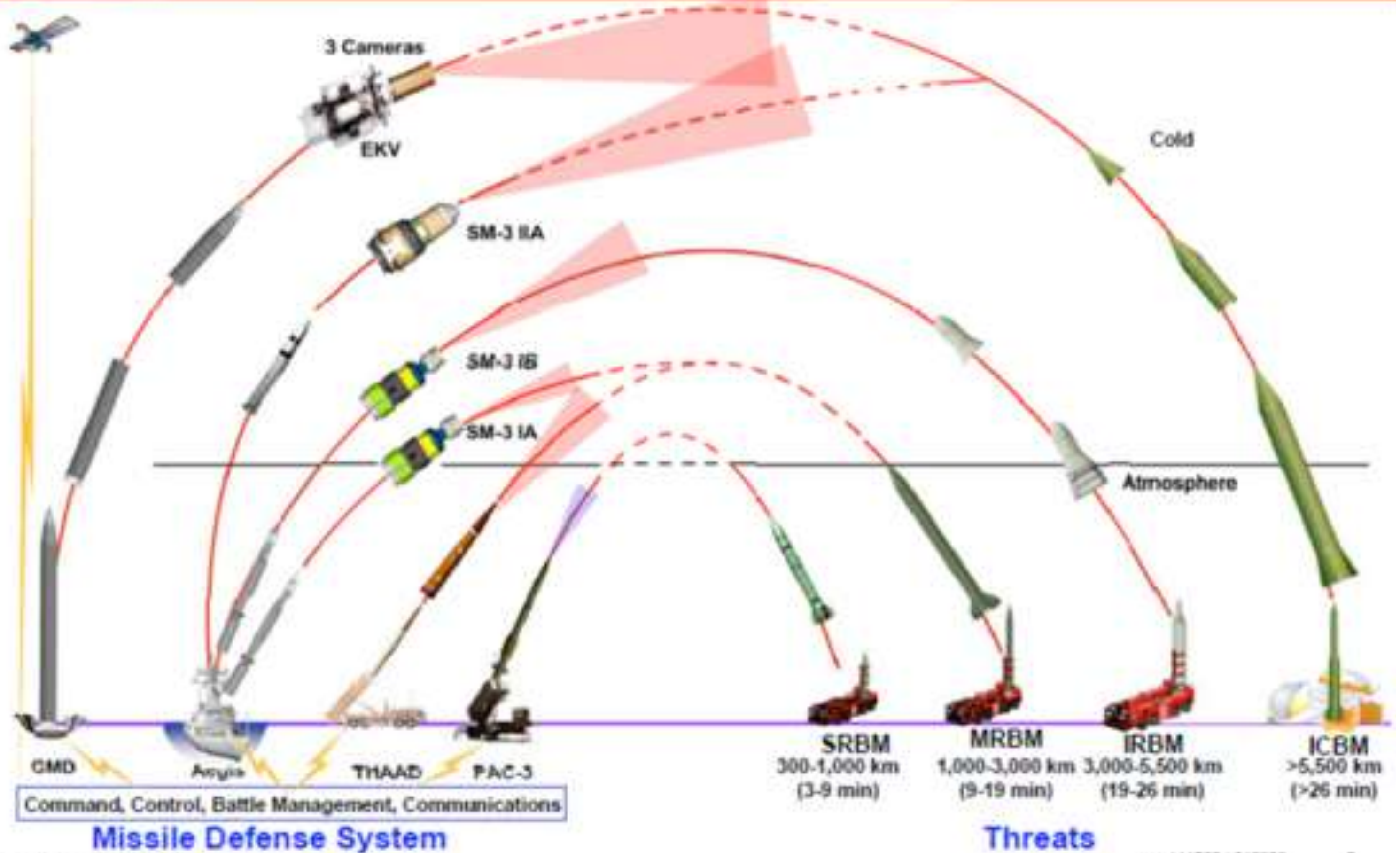




Space Operational Challenges







SHORT ACCESS TIMES 短暫視線通訊時間

LEO line of sight limited.

Orbital velocity 7 – 8 km s^{-1}

LONG OPERATIONAL DURATION 連續有效工作時間

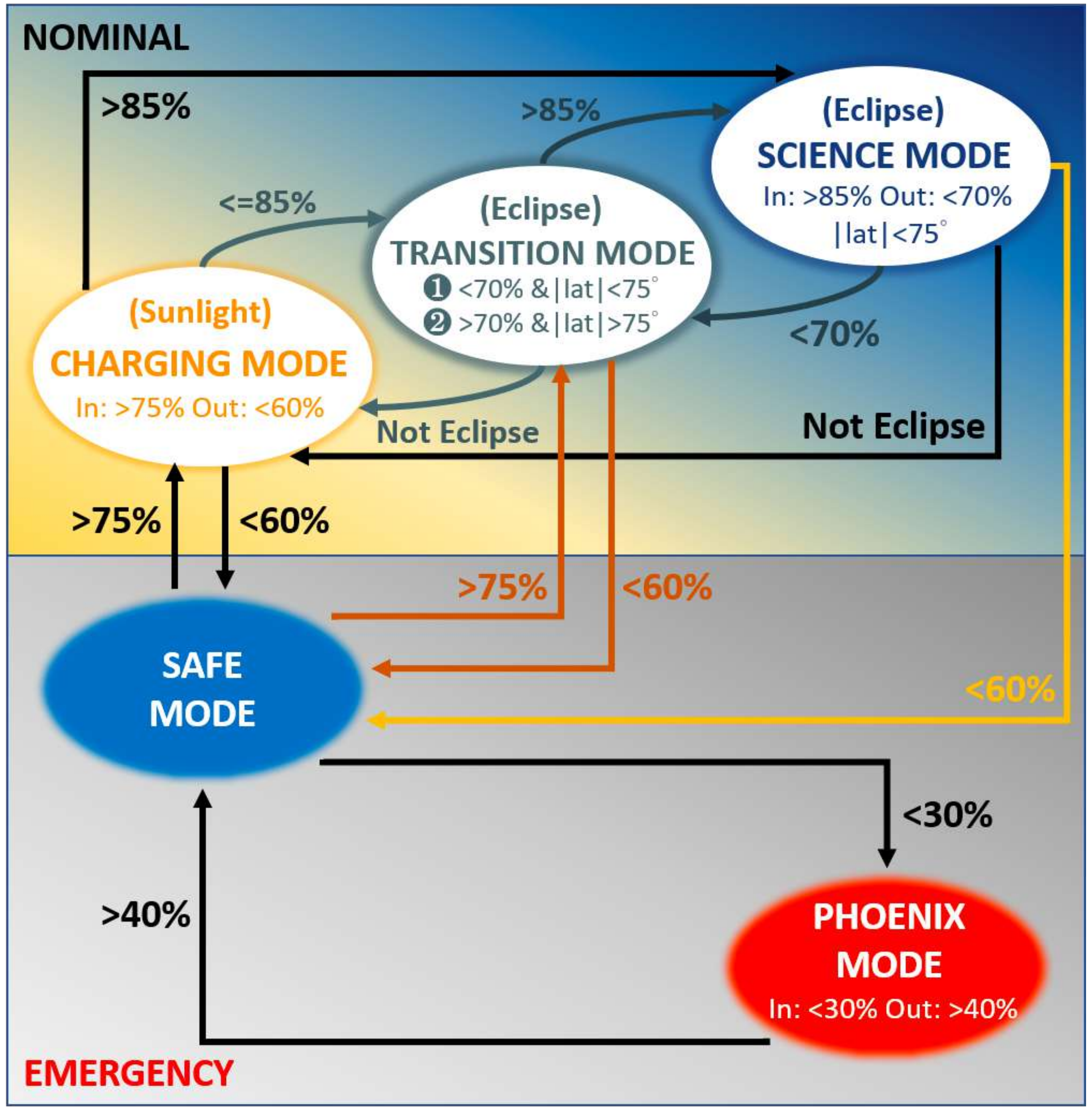
Missile: Minutes

Aircraft & Launch Vehicles: Hours

Satellites: Months to Years

IDEASSat Flight Software

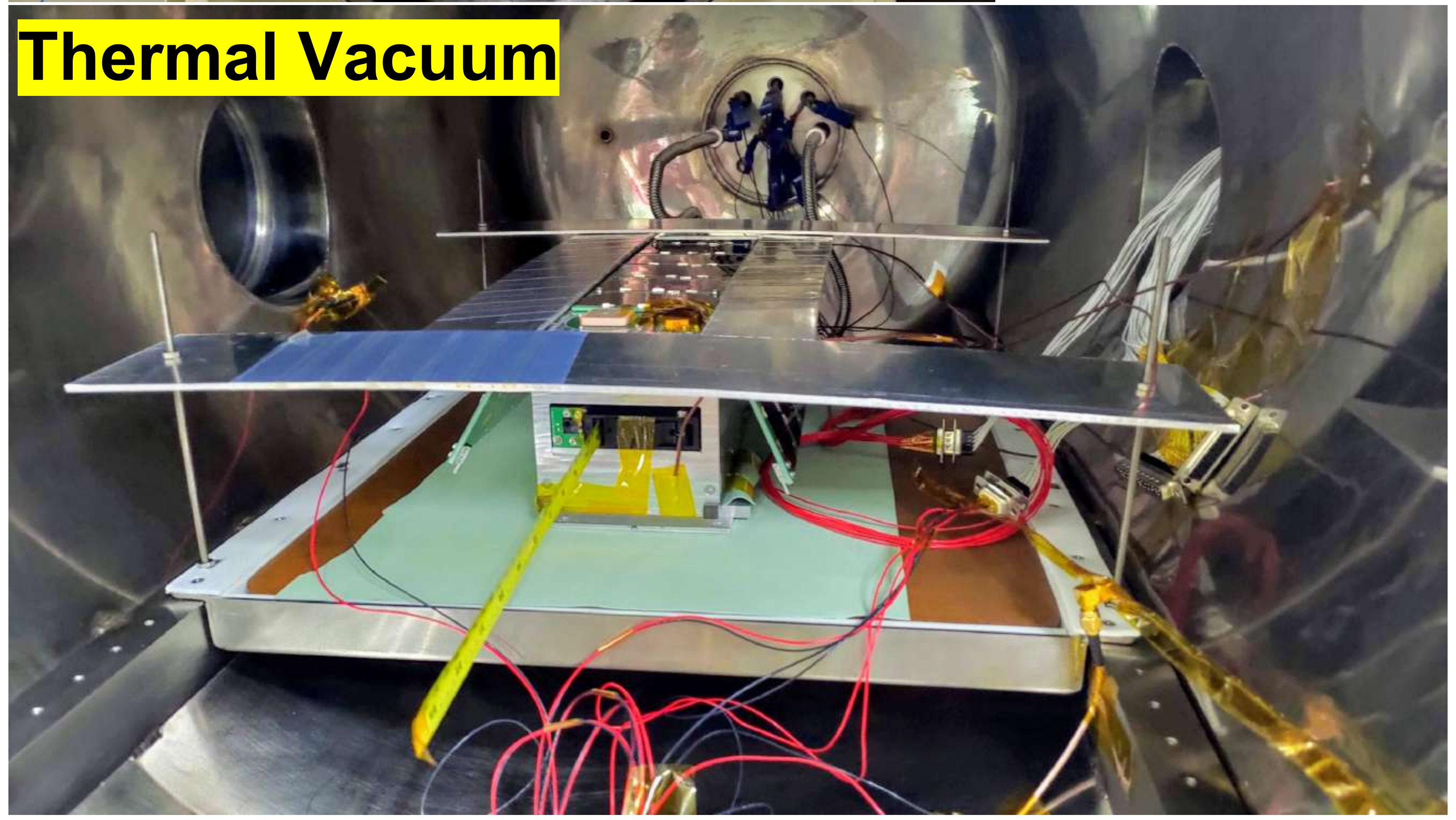
IDEASSat Operational Modes					
Mode	**EMERGENCY**		**NOMINAL**		
State	**Phoenix**	**Safe**	**Charging**	**Science**	**Transition**
EPS	ON	ON	ON	ON	ON
ADCS	OFF	Sun Point	Sun Point	LVLH	LVLH
CDH	ON	ON	ON	ON	ON
UHF(Tx)	BEACON	BEACON	BEACON	BEACON	BEACON
UHF(Rx)	ON	ON	ON	ON	ON
S-Band(Tx)	OFF	OFF	AS REQ	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		



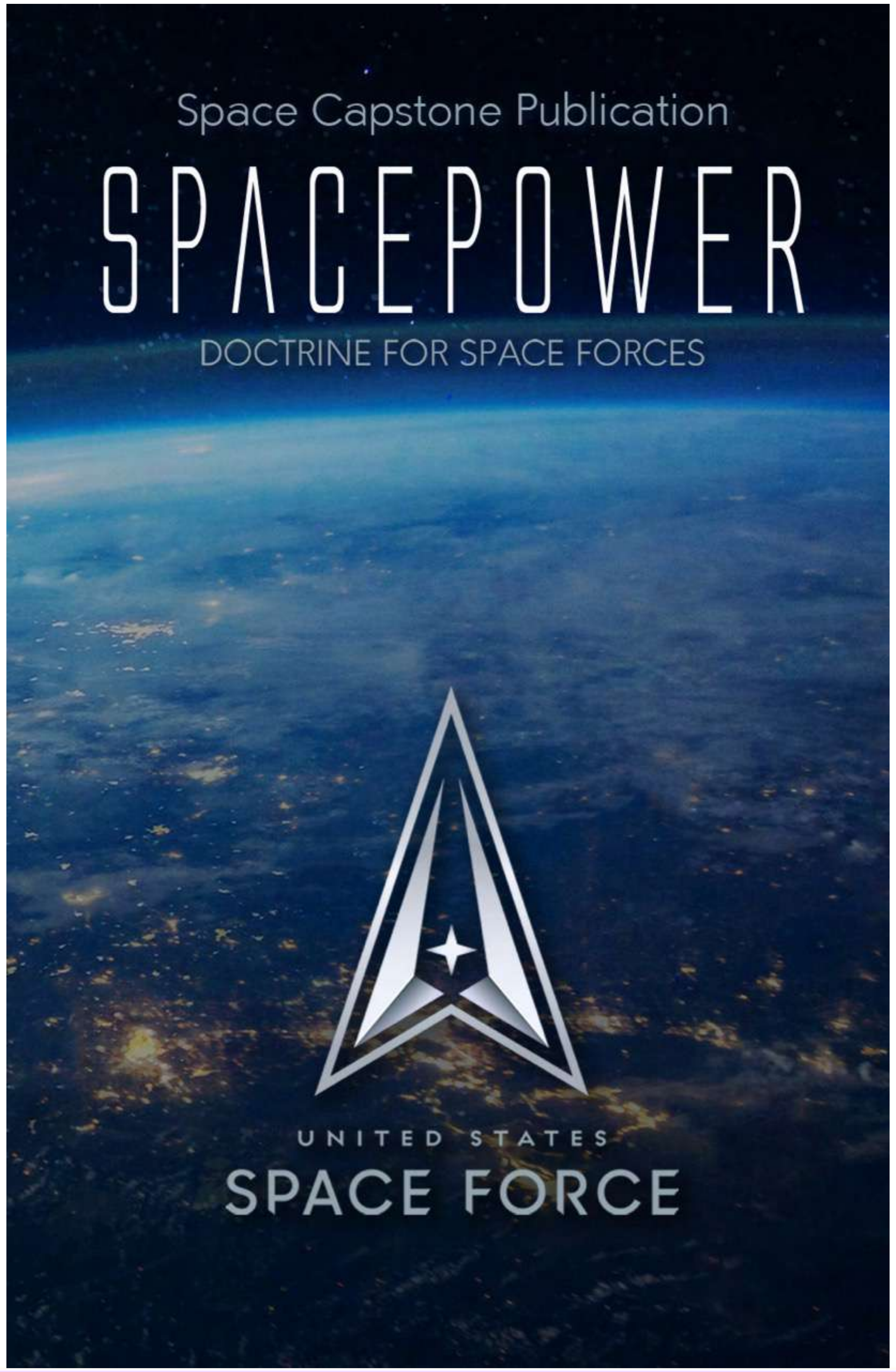
Environmental Testing (Minimal)

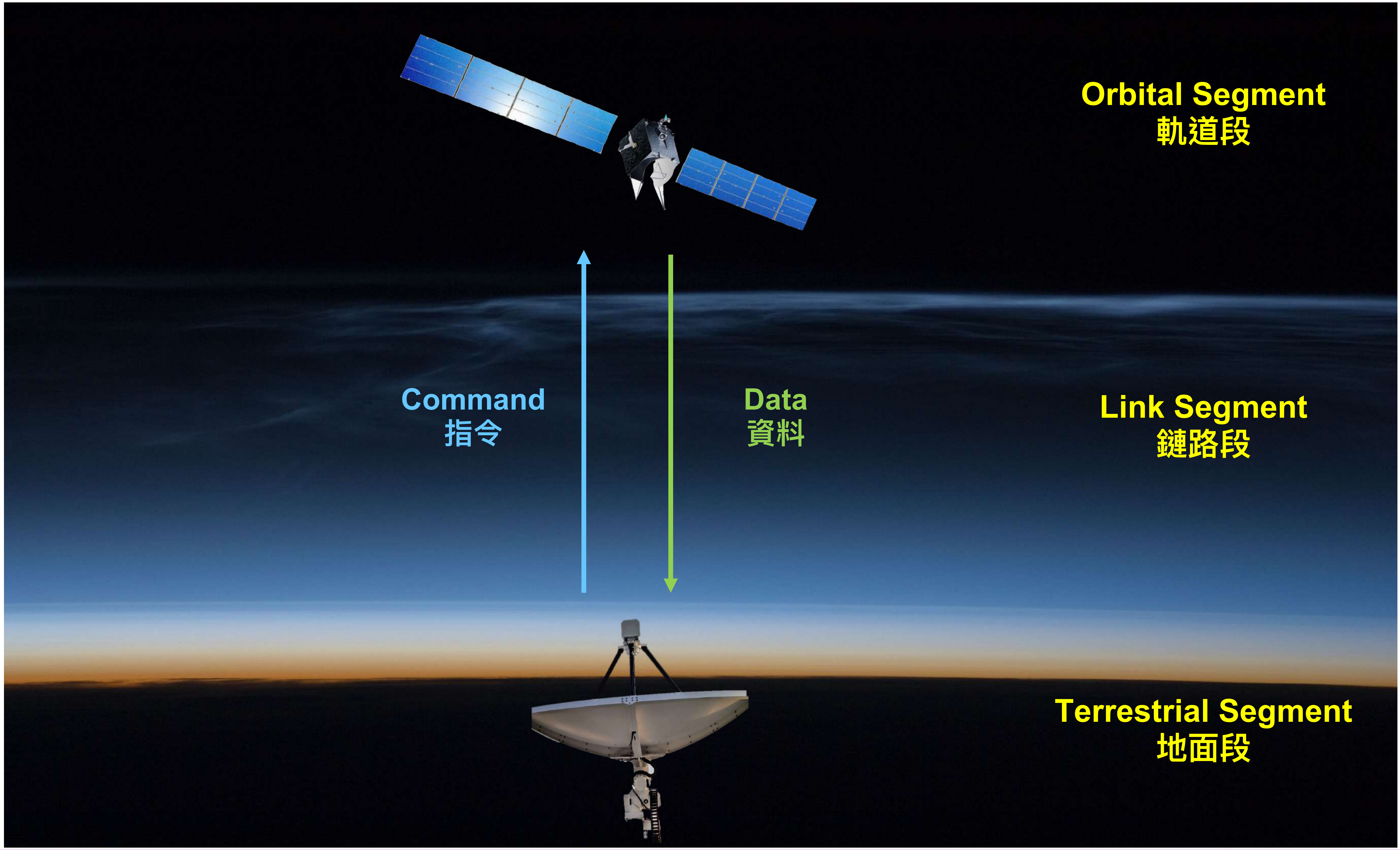
Table 3-13: Payload Unit Test Levels and Durations

Test	Fleet Qualification Approach		Single unit Approach	Required or Advised
	Qualification	Acceptance	Protoqualification	
Shock	6 dB above MPE, 3 times in each of 3 orthogonal axes	Not Required	3 dB above MPE, 2 times in each of 3 orthogonal axes	Required[2]
Acoustic	6 dB above acceptance for 2 minutes	Envelope of MPE and minimum spectrum for 1 minute	3 dB above acceptance for 1 minutes[1]	Advised
Random Vibration	6 dB above acceptance for 2 minutes in each of 3 axes	Envelope of MPE and minimum spectrum for 1 minute in each of 3 axes	3 dB above acceptance for 1 minutes in each of 3 axes[1]	Required
Combined Thermal Vacuum and Thermal Cycle[3]	±10°C beyond acceptance for 27 cycles total	Envelope of MPT and minimum range (–24 to 61°C) for 14 cycles total	±5°C beyond acceptance for 20 cycles total	Advised
Static Load[4]	1.25 times the limit load	1.1 times the limit load	1.25 times the limit load	Required
Pressure	Pressures as specified in Table 6.3.12-2 of SMC-S-016 following acceptance proof pressure test, duration sufficient to collect data	1.25 times MEOP for pressure vessels; 1.5 times MEOP for pressure components. Other metallic pressurized hardware items per References 4 and 5 from SMC-S-016	Not Applicable at the Payload Level[5]	Required
Electromagnetic Compatability[6]	No Margin	Not Applicable	No Margin	Required

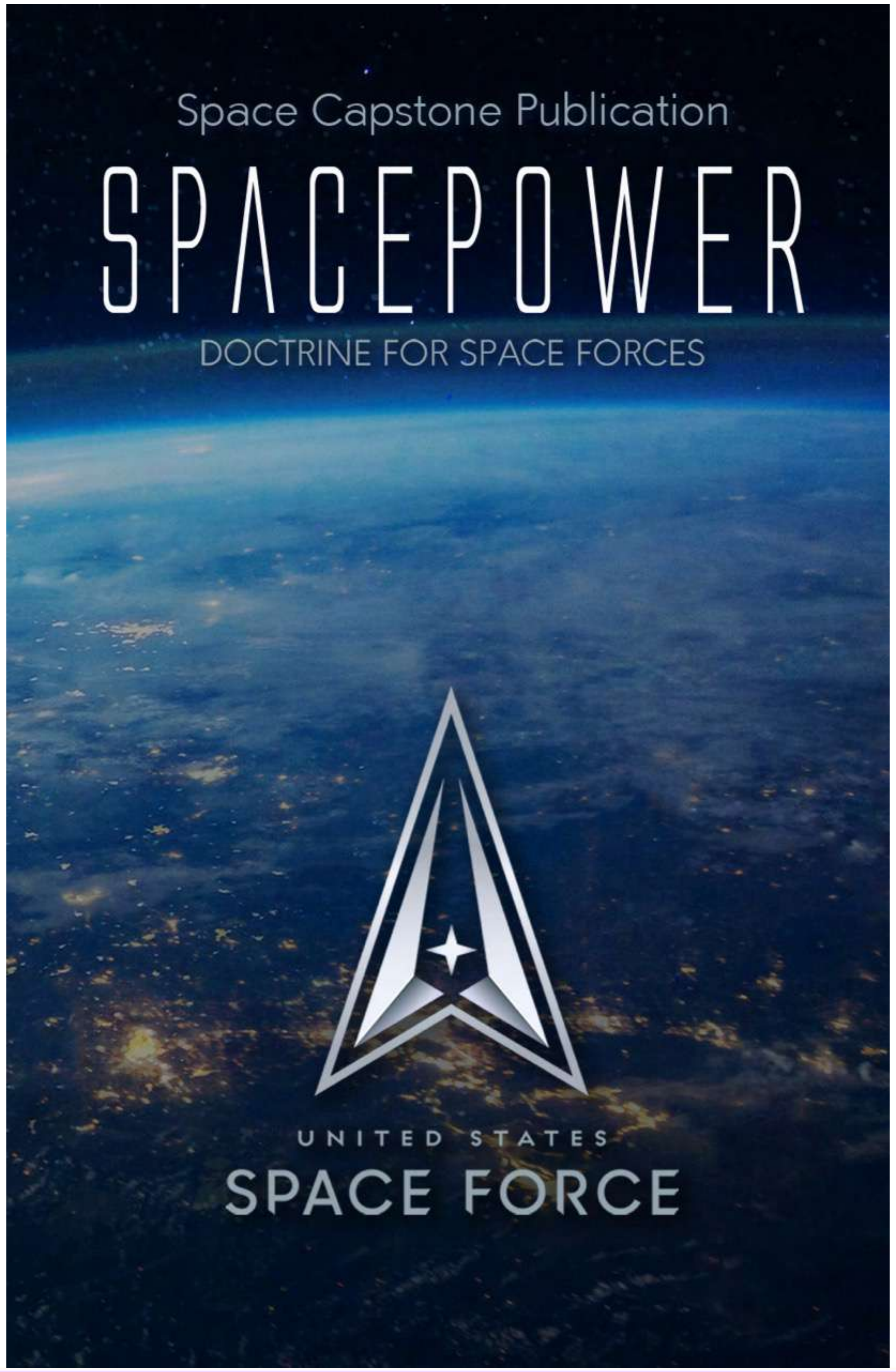


太空系統架構

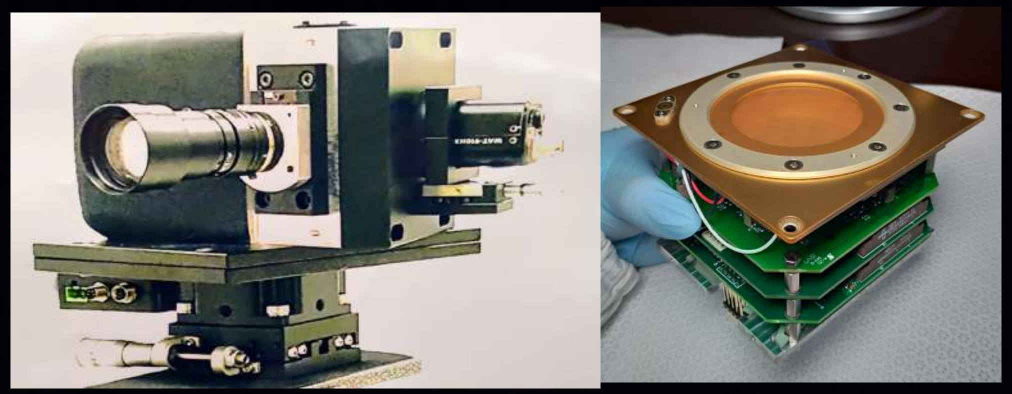

Space Capstone Publication
SPACEPOWER
DOCTRINE FOR SPACE FORCES
UNITED STATES
SPACE FORCE


Orbital Segment
軌道段
Command
指令
Data
資料
Link Segment
鏈路段
Terrestrial Segment
地面段

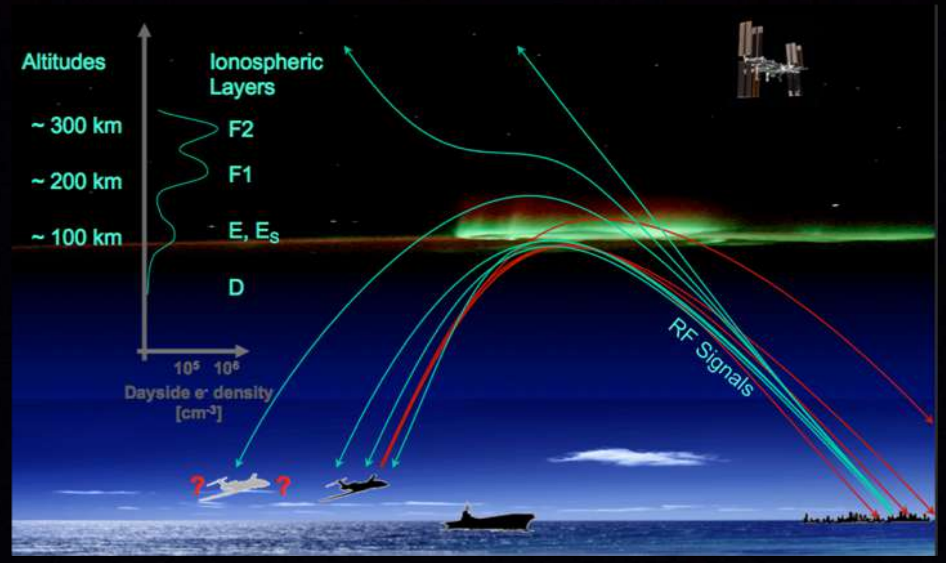
太空系統架構



自製衛星



衛星酬載與元件

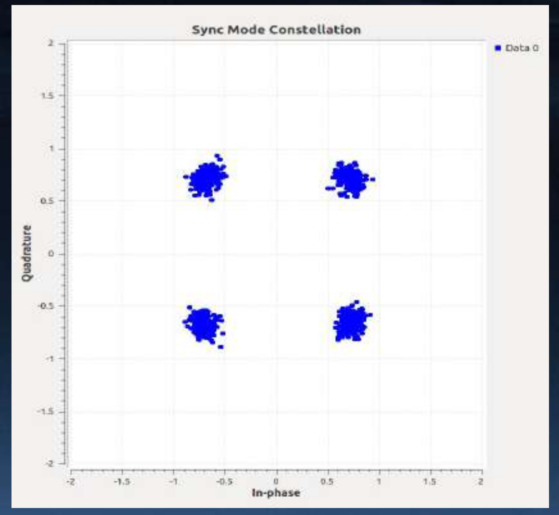


應用太空環境研究

Orbital Segment
軌道段

地面接收站

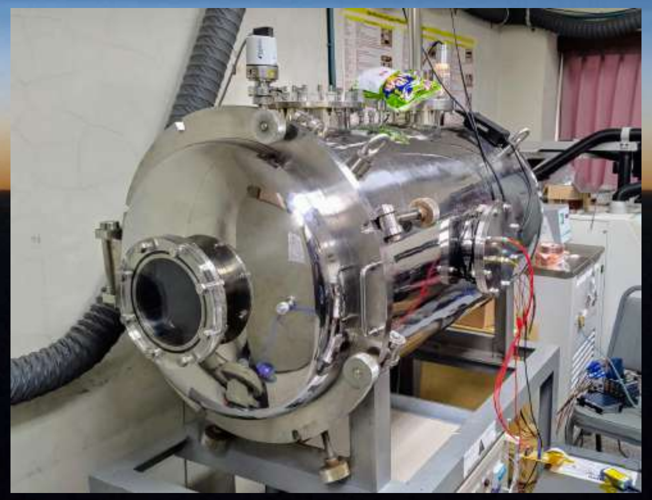
通訊次系統整測



訊號處理

Link Segment
鏈路段

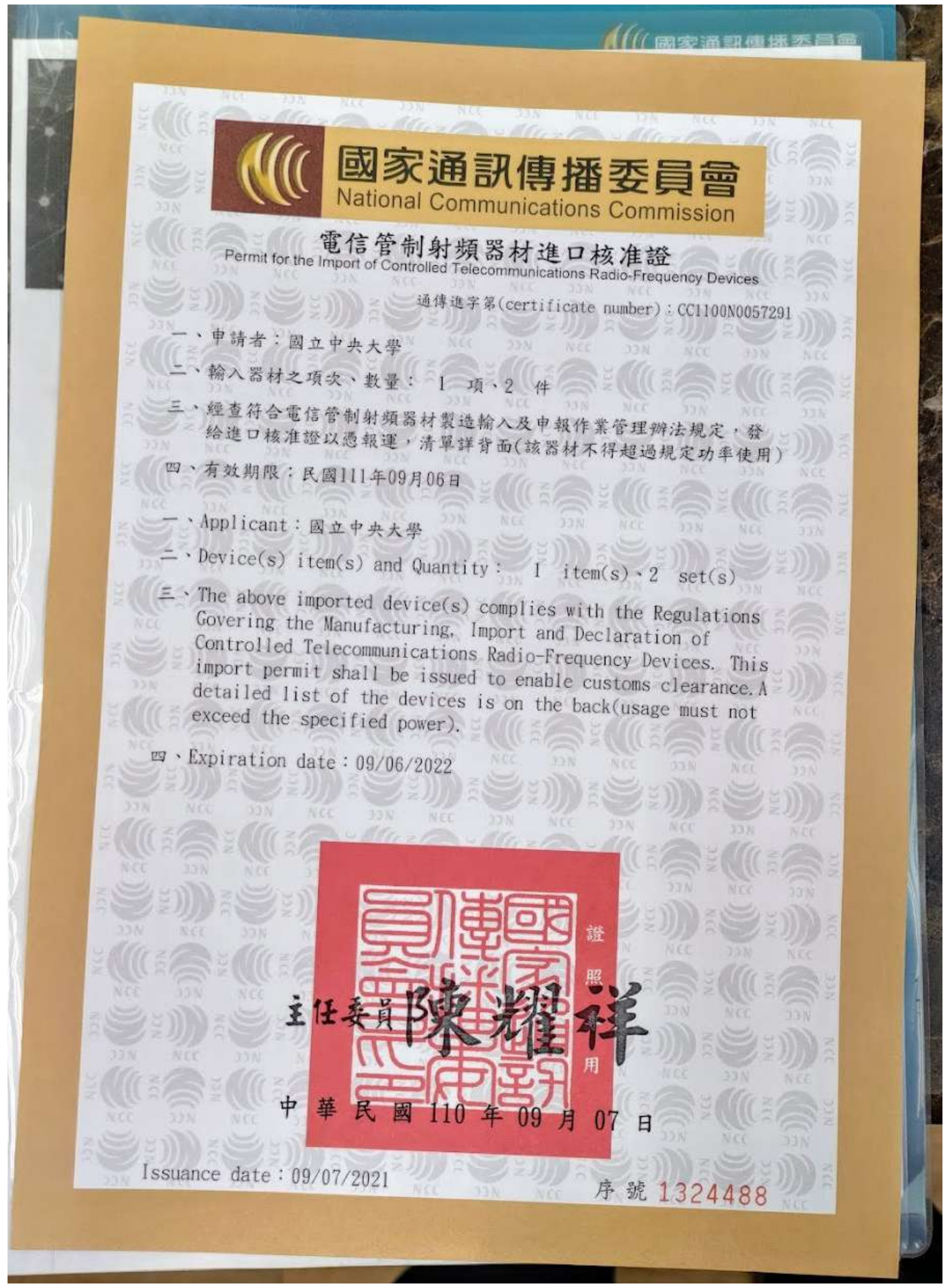
衛星作業中心



衛星環測設施

Terrestrial Segment
地面段

Communications Regulation


國家通訊傳播委員會
National Communications Commission

電信管制射頻器材進口核准證
Permit for the Import of Controlled Telecommunications Radio-Frequency Devices

通傳進字第(certificate number)：CCI100N0057291

一、申請者：國立中央大學
二、輸入器材之項次、數量： 1 項、2 件
三、經查符合電信管制射頻器材製造輸入及申報作業管理辦法規定，發給進口核准證以憑報運，清單詳背面(該器材不得超過規定功率使用)
四、有效期限：民國111年09月06日

一、Applicant：國立中央大學
二、Device(s) item(s) and Quantity： 1 item(s)、2 set(s)
三、The above imported device(s) complies with the Regulations Govering the Manufacturing, Import and Declaration of Controlled Telecommunications Radio-Frequency Devices. This import permit shall be issued to enable customs clearance. A detailed list of the devices is on the back(usage must not exceed the specified power).
四、Expiration date：09/06/2022

主任委員 陳耀祥
中華民國 110 年 09 月 07 日
Issuance date：09/07/2021
序號 1324488

NCC Import Permit Required for RF Components:
專案暫時進口加工後出口

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.)

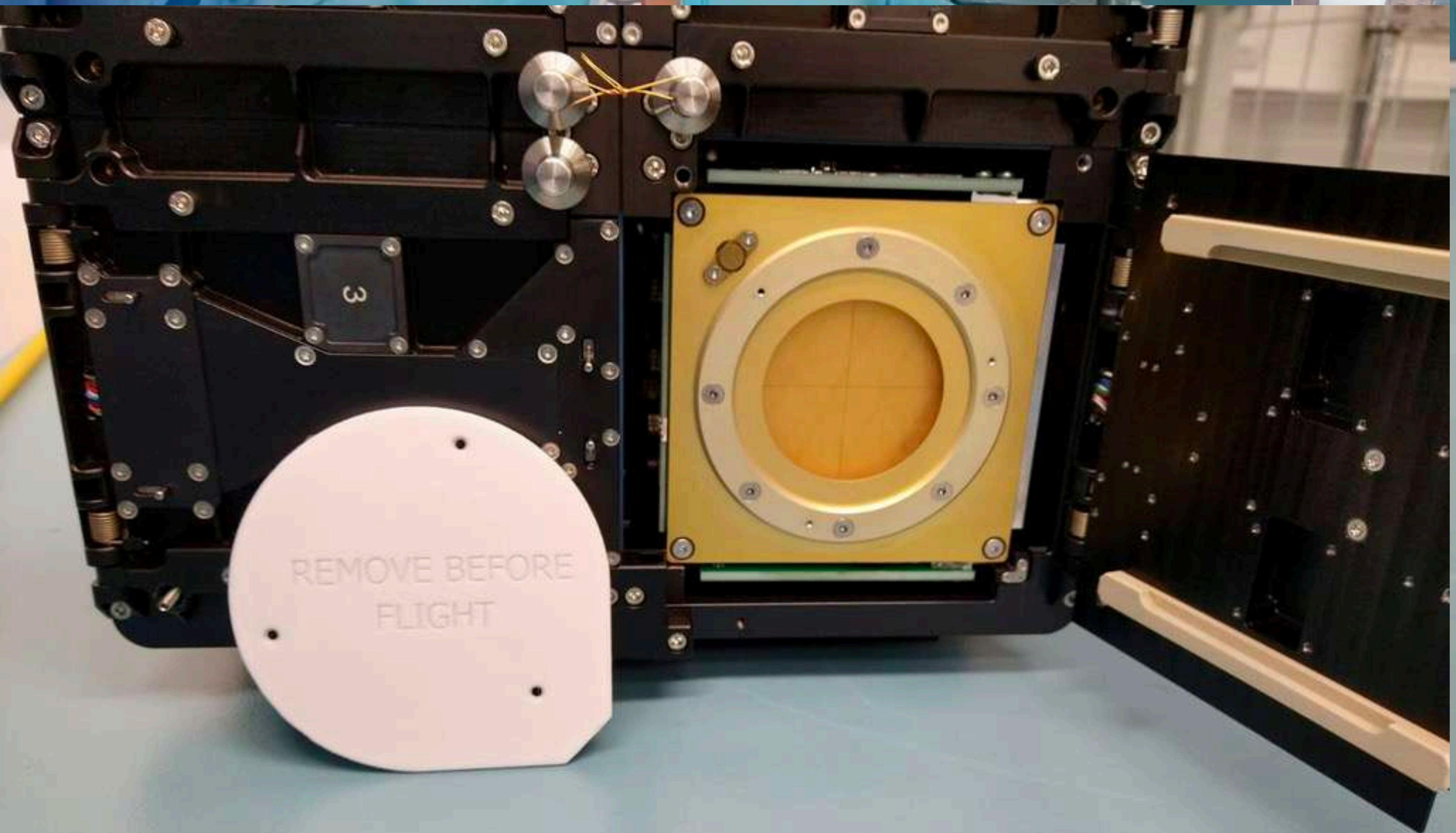
Have you read the instructions? Here is the link
http://www.iaru.org/uploads/1/3/0/7/13073366/instructions_iaru_amateur_satellite_coordination_request.doc
Please do NOT submit the request before it is 100% filled and signed.

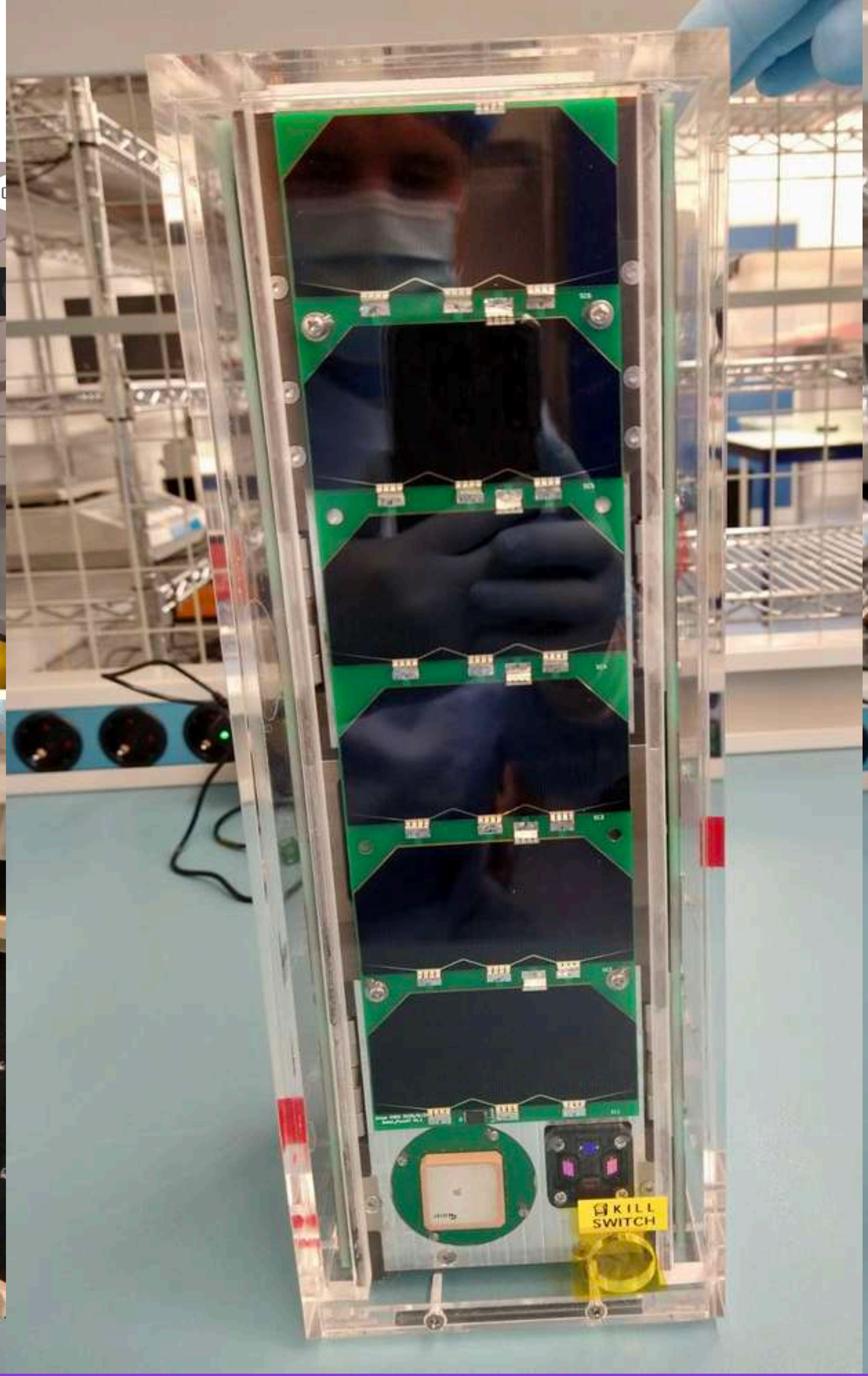
Administrative information:

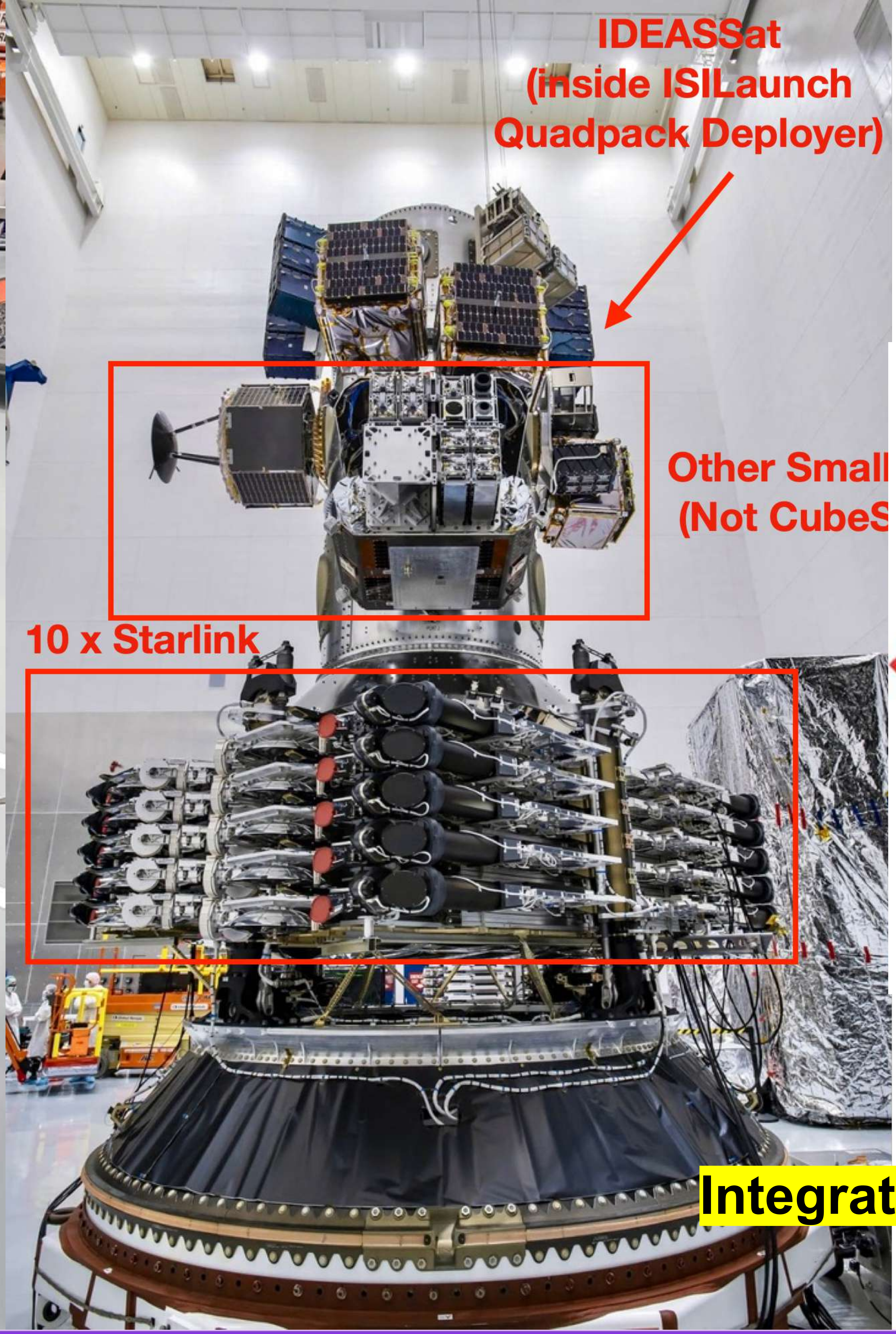
0	**DOCUMENT CONTROL**	
0a	Date submitted	2019/10/18
0b	Document revision number	NCU-001
1	**SPACECRAFT (published)**	
1a	Name	IDEASSat
1b	Notifying administration	National Central University
1c	API/A number	

Frequency Coordination required from International Amateur Radio Union (IARU):
Problem – Taiwan not International Telecommunication Union (ITU) member.
Cannot submit Advance Publication Information.

Deployment Pod Insertion
2020/12/01



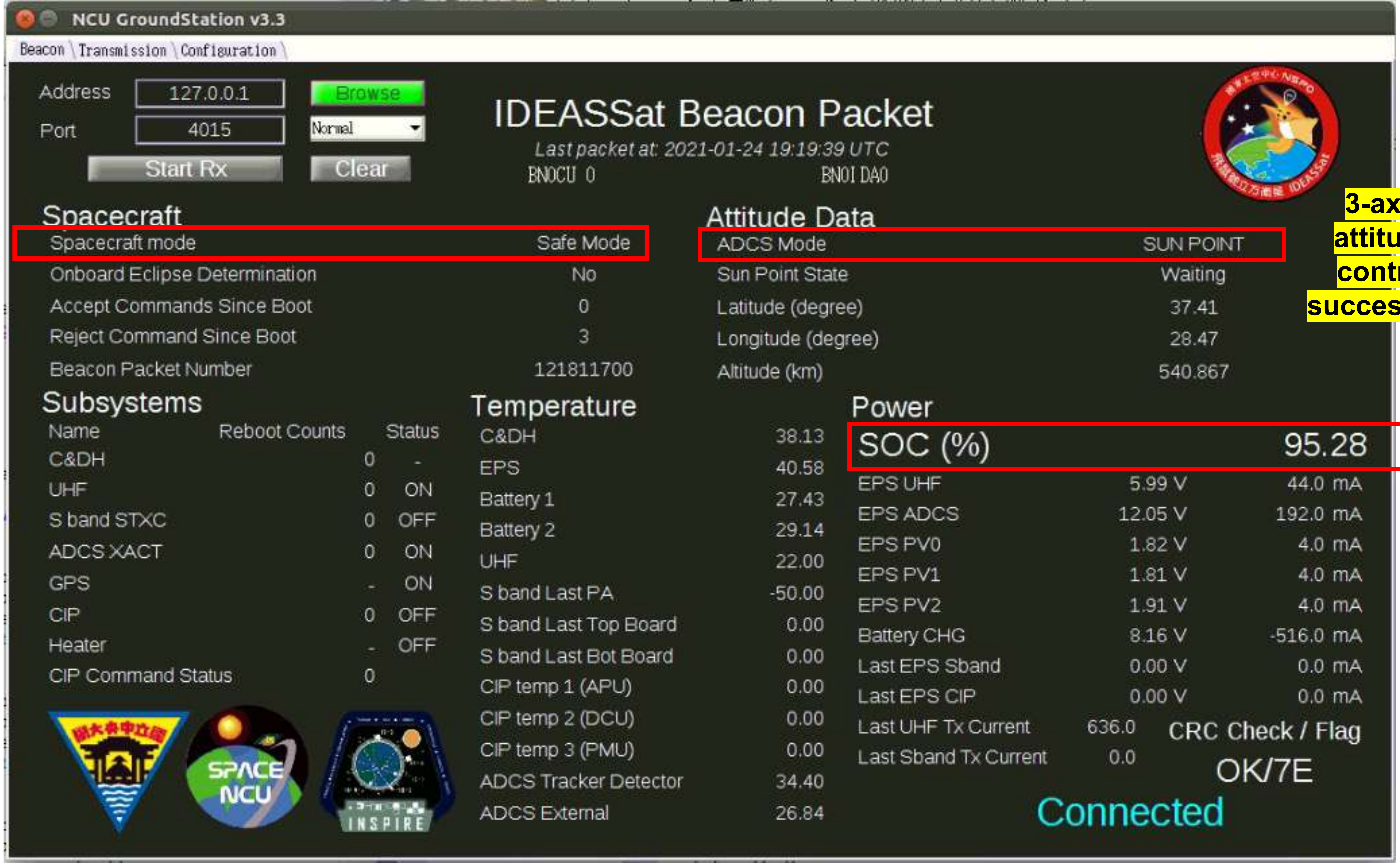




Integration with launch vehicle
2020/12/22

SpaceX Falcon 9 Launch
2021/01/24

Spacecraft powered on successfully into Safe mode.

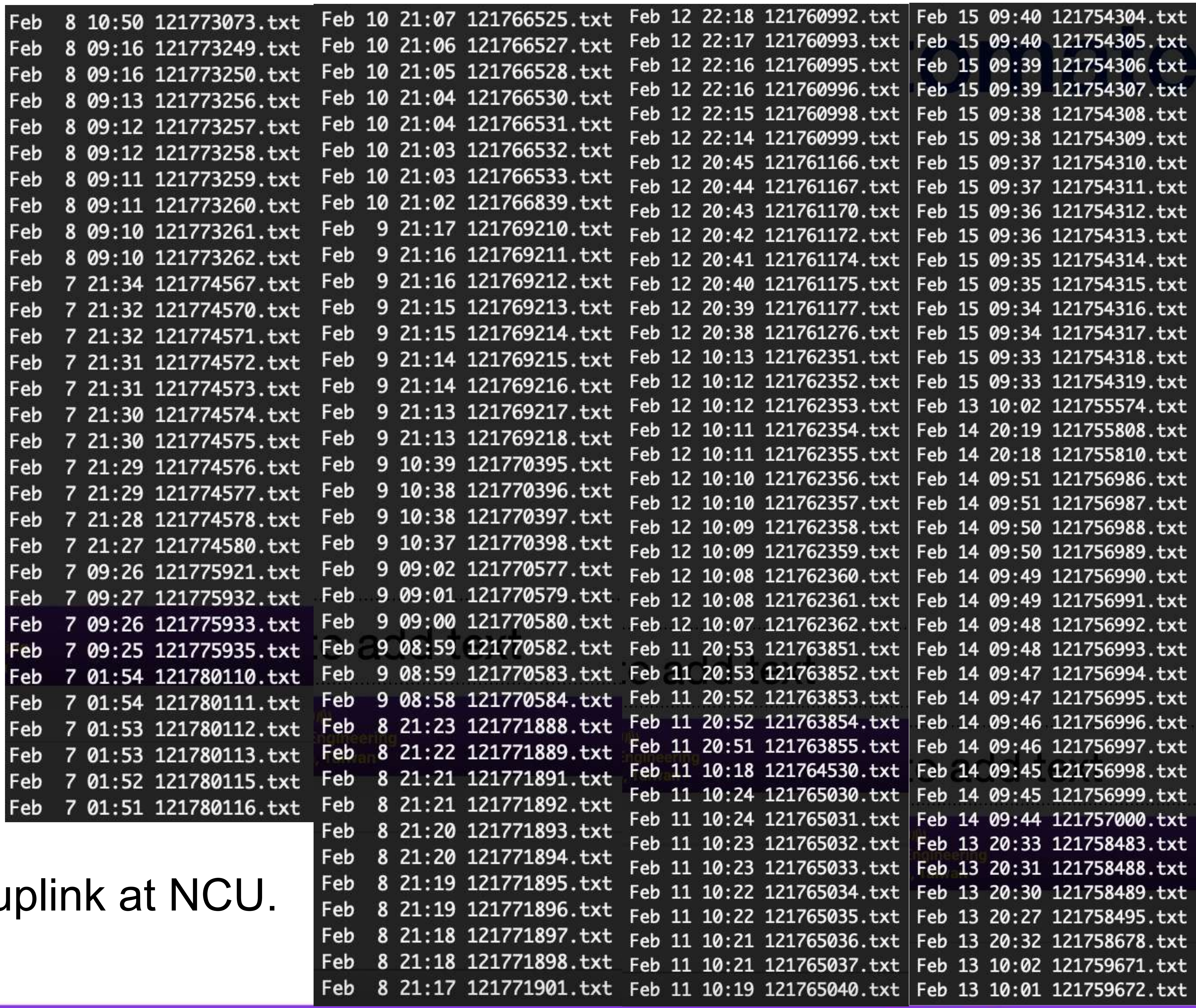


3-axis attitude control successful!

Battery state of charge very healthy!

First flight data beacon received from SatNOGS (amateur radio network): T + 4 hours.

Automated Real Time Downlink



- Spacecraft range: 522 – 2600 km.
- Automated tracking, flight data downlink, command uplink at NCU.
- Over 700 counts of flight data.

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

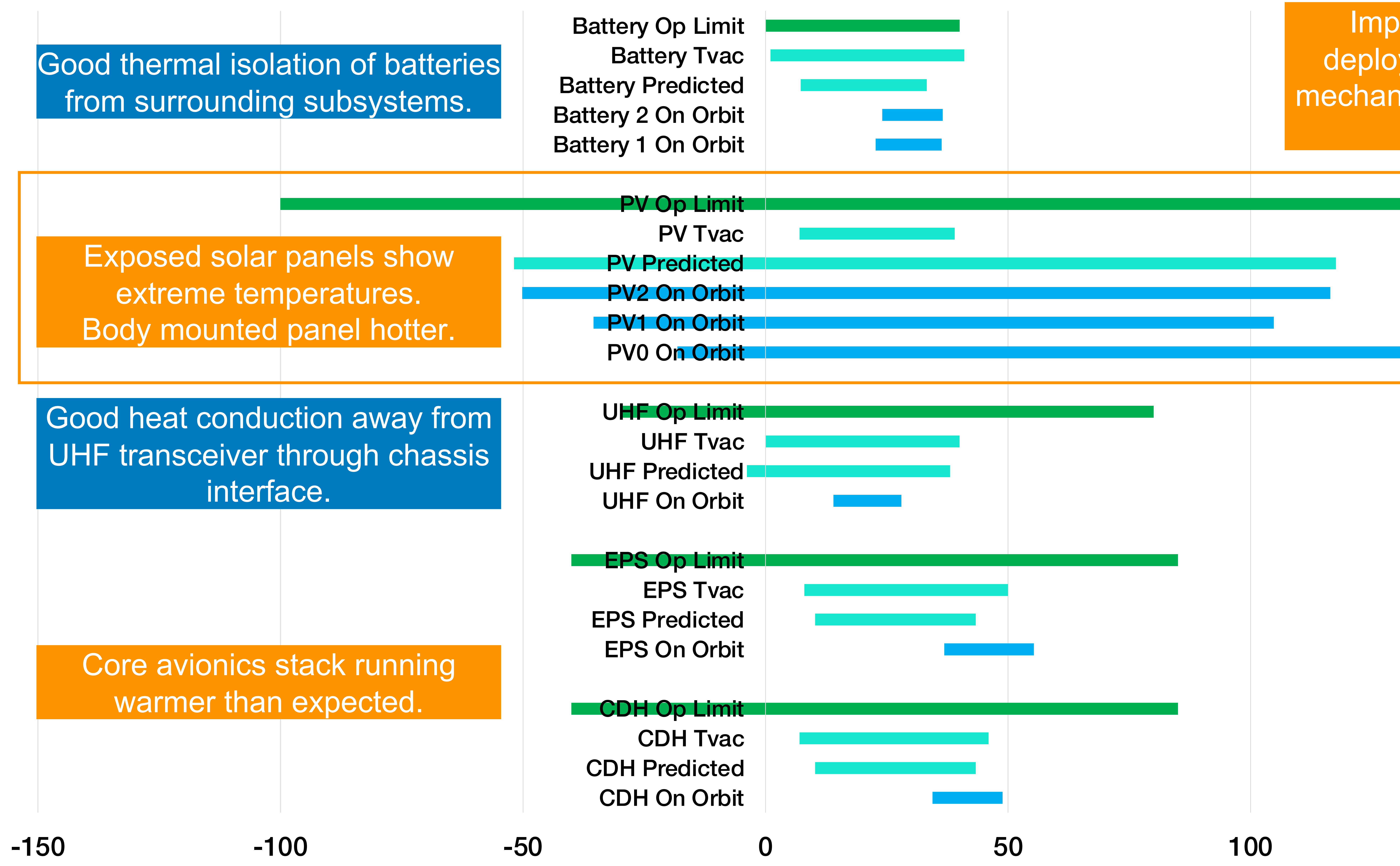
Good thermal isolation of batteries from surrounding subsystems.

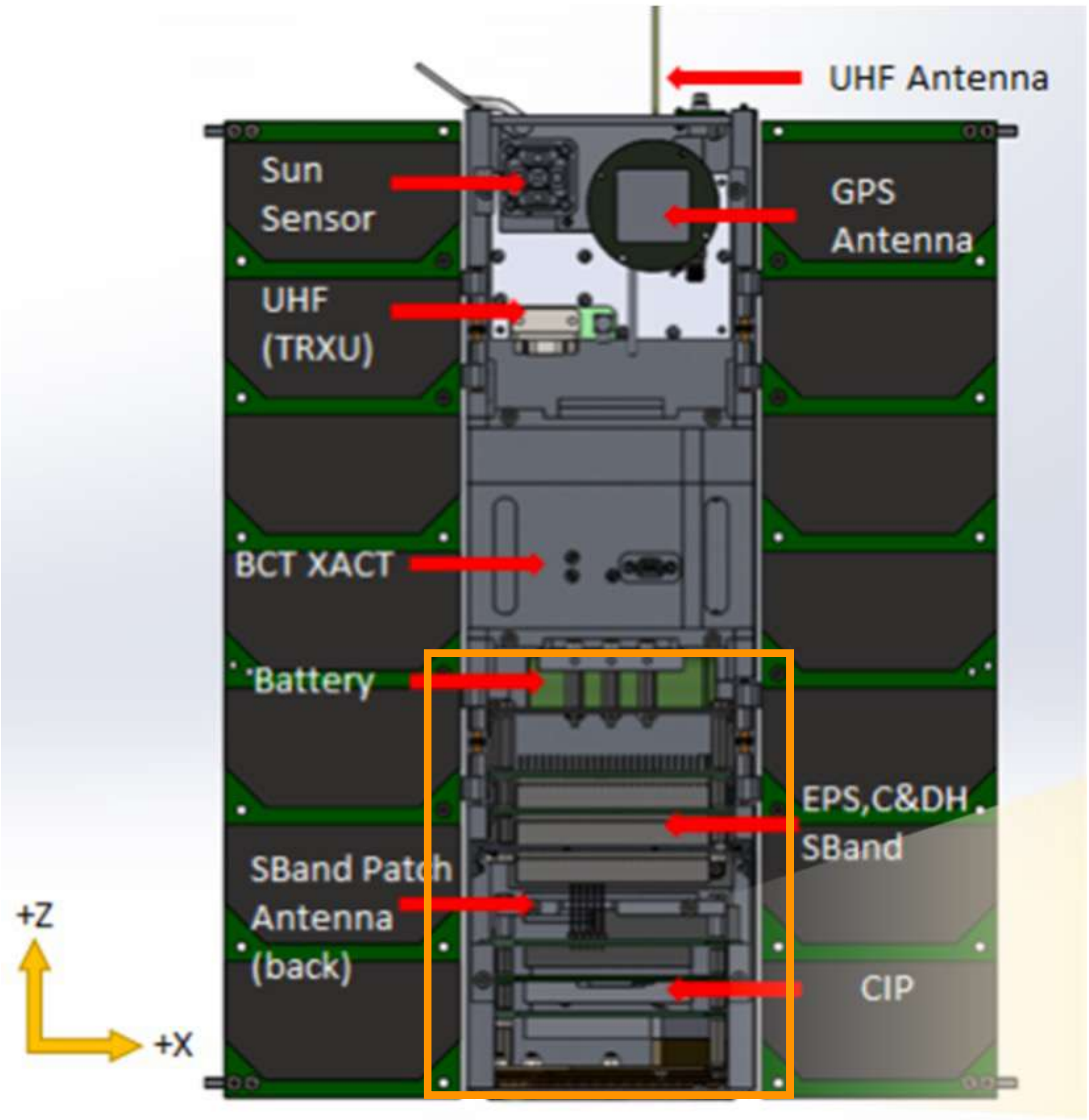
Improvements needed in deployable solar panel hinge mechanism and solar panel PCB fabrication.

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

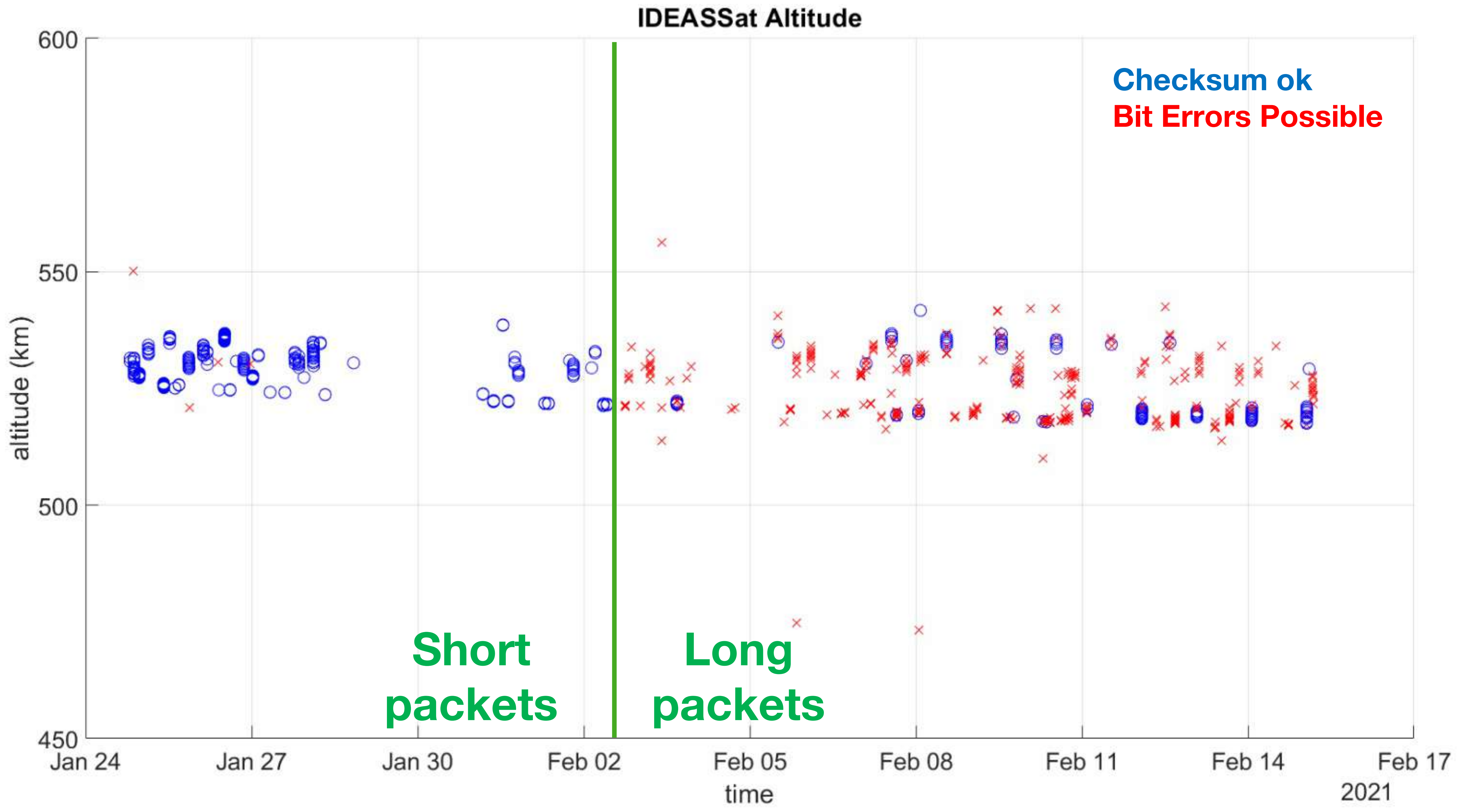
Good heat conduction away from UHF transceiver through chassis interface.

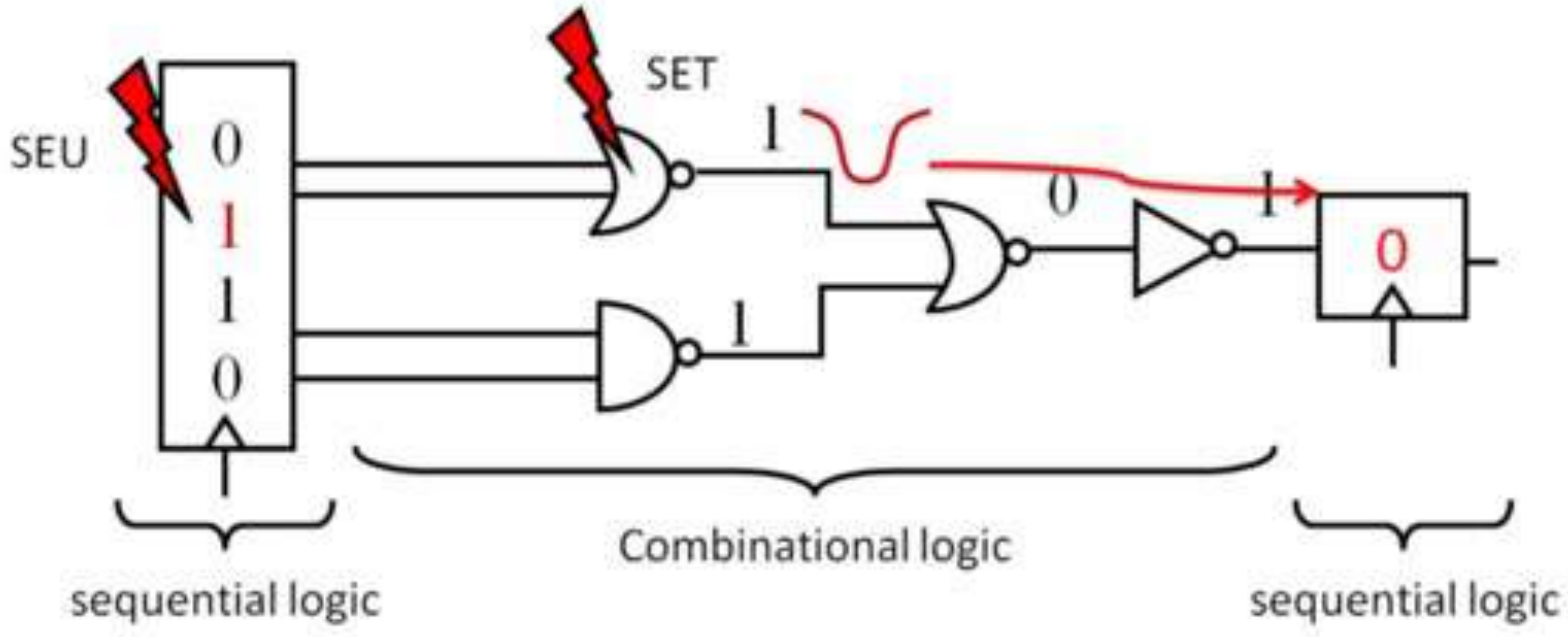
Core avionics stack running warmer than expected.





Anomaly: Probable Single Event Upset (SEU單事件翻轉)

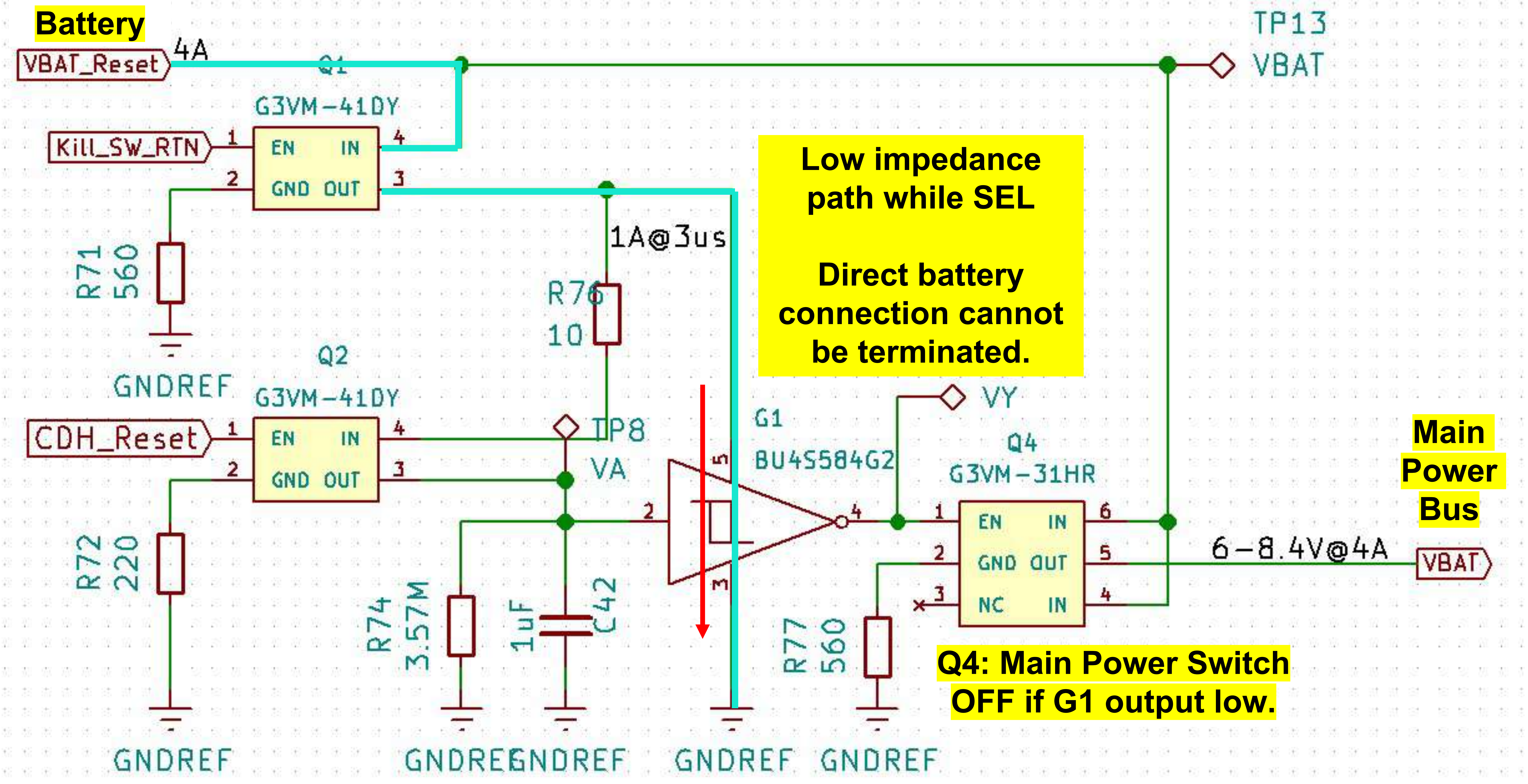





```
CDH
   CDH Reboot Count : 0
   CDH Command Accept Count Since Boot : 0
   CDH Command Reject Count Since Boot : 28
   CDH Last Command APID :
```

SEU resulted in FSW parameter change without command. Error Correction Code needed for FSW variables, especially those logged to non-volatile memory.

IDEASSat EPS Main Power Bus Circuit

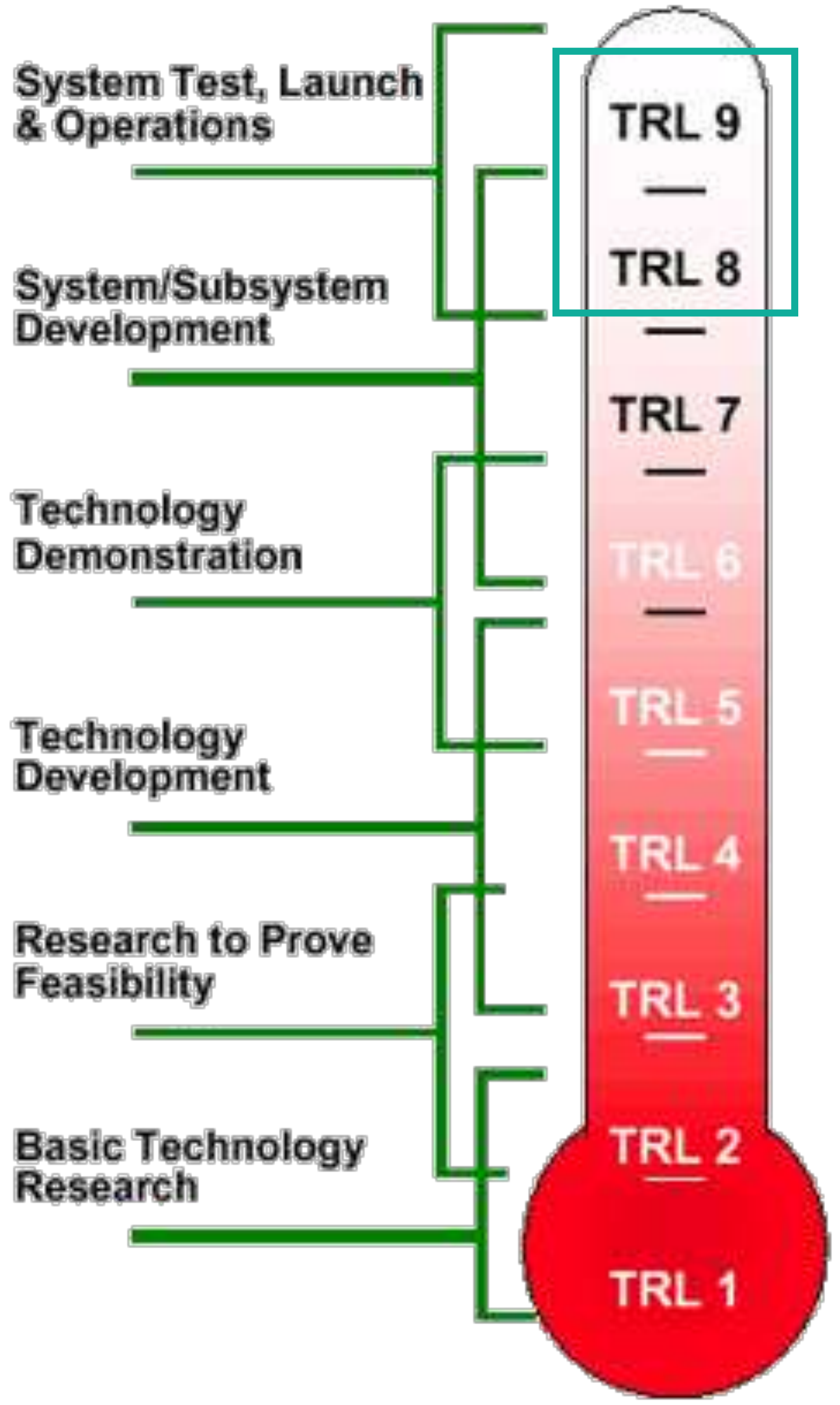


- COMM blackout for 1.5 months at T+22 days. Flight data downlinked after recovery used to identify cause.
- G1 CMOS IC at risk of single event latchup (SEL) from energetic ion strike, which will power down entire spacecraft until cleared.
- SEL cannot be cleared until sufficient discharge of battery.
- EPS redesigned to include overcurrent protection for SEL recovery.

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

Conclusions

Technological Readiness Level (TRL)



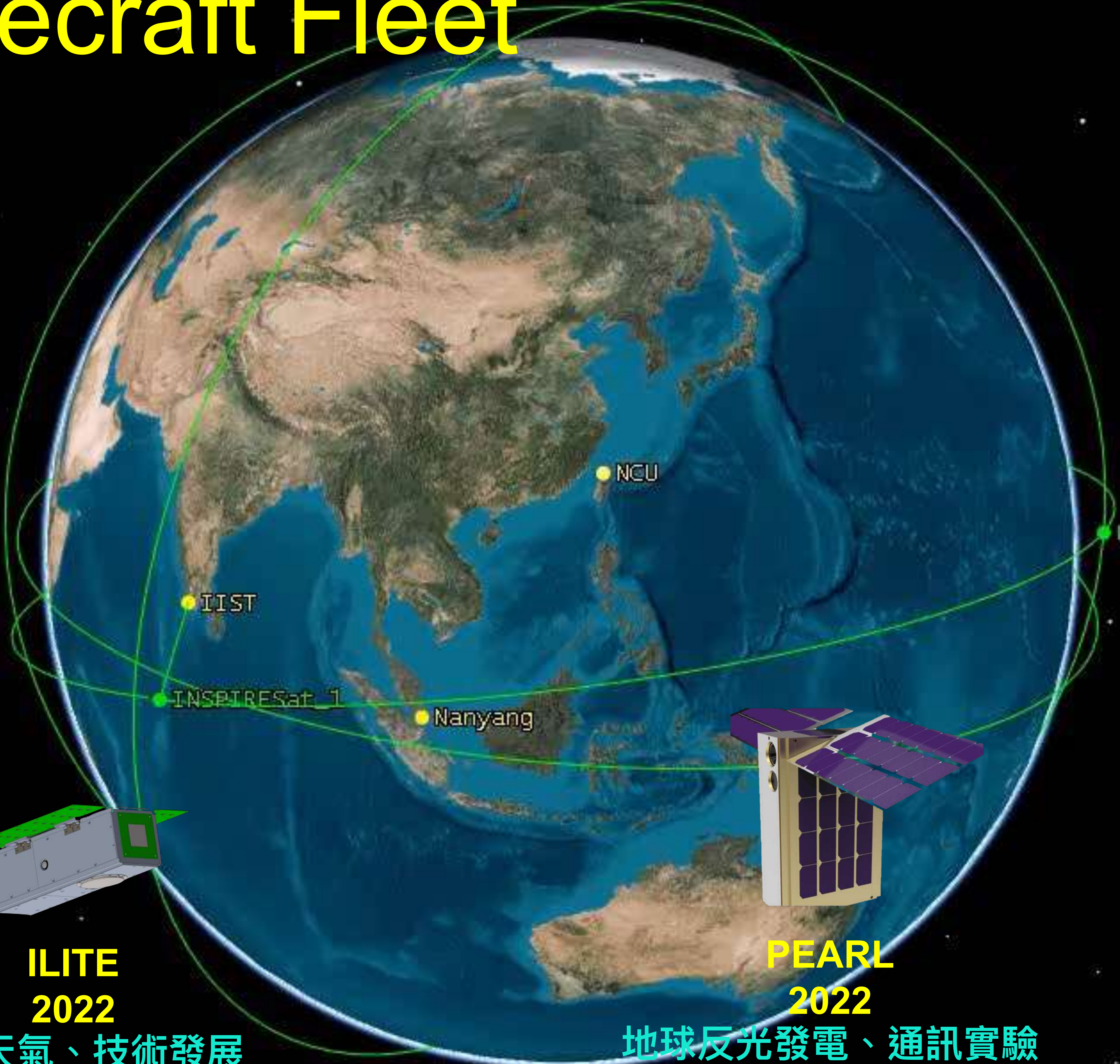
- **Design:** Spacecraft functions were capable of ensuring excellent power, link, and thermal margins, as well as 3-axis attitude control, two way communication, and return of flight data on orbit. Modifications to self-developed EPS necessary for single event latchup protection.

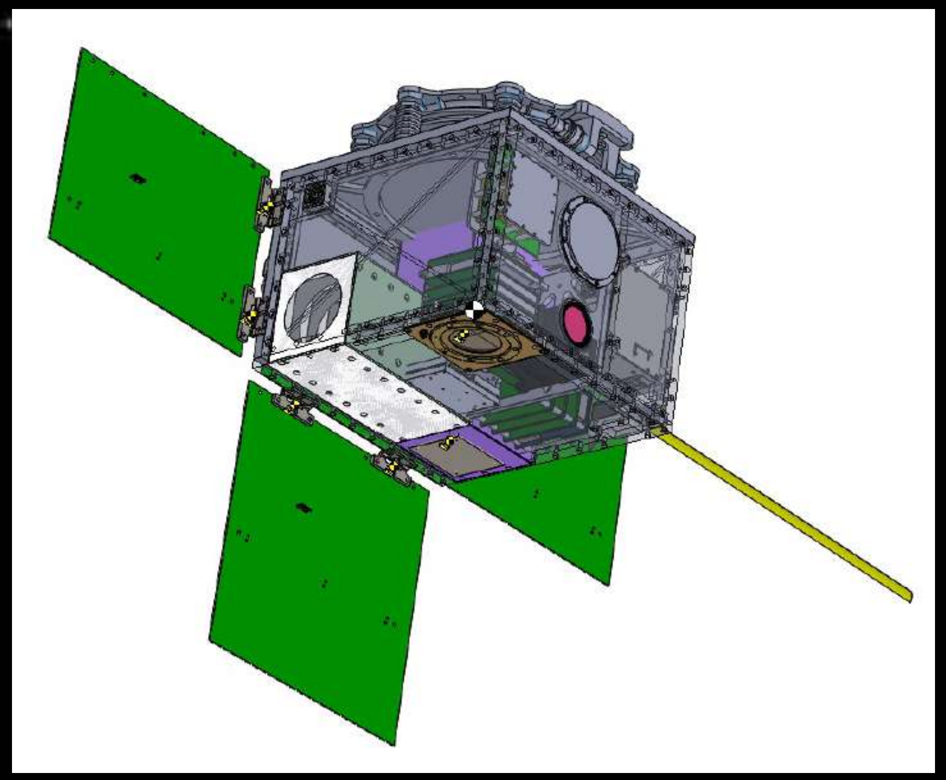
- **Workmanship**: Spacecraft survived launch environment, successfully activated and operated autonomously on orbit.

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

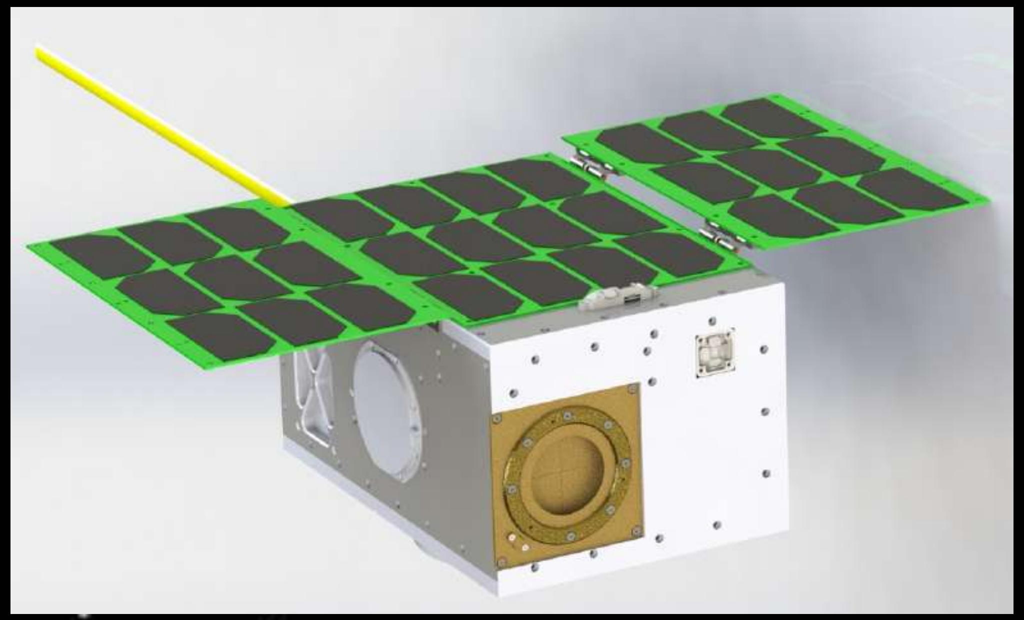
Work being performed to improve robustness of self-developed avionics to allow for reliable operation over at least 1 year.

Our Spacecraft Fleet





ARCADE
2023
太空天氣、遙測、極低軌道
國際合作整合

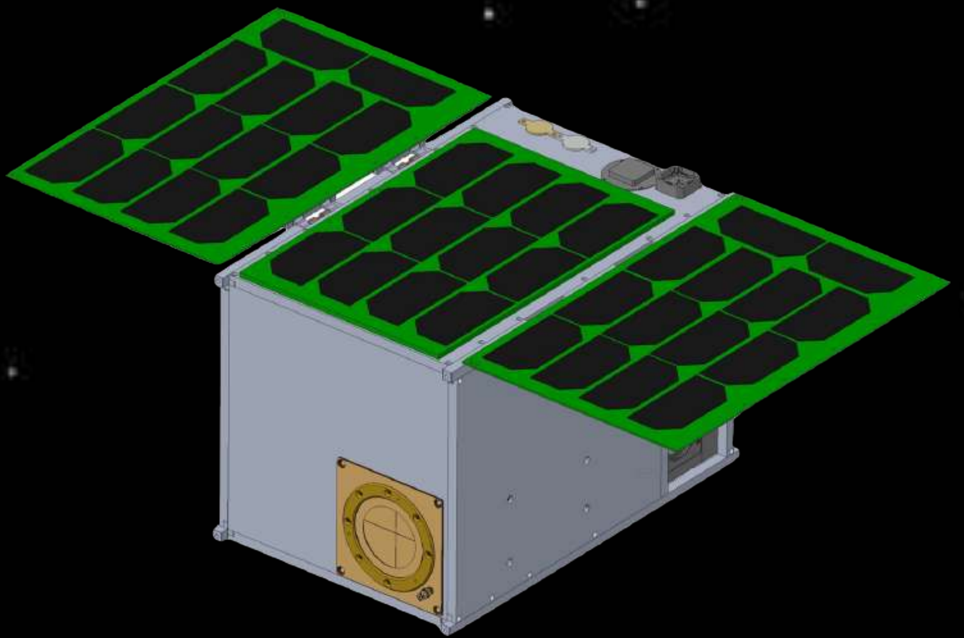


INSPIRESat-1
2022
太空天氣、技術發展
國際合作整合

IDEASSat-1
2021
太空天氣、技術發展
自主整合

ILITE
2022
太空天氣、技術發展
自主整合

PEARL
2022
地球反光發電、通訊實驗
自主酬載、外購COTS本體



SCION-X
2023
太空天氣、遙測、技術發展
自主整合

SCIENCE

INSPIRESat-1 primed for launch, says Indian Institute of Space Science and Technology

Tiki Rajwi

THIRUVANANTHAPURAM, SEPTEMBER 04, 2021 19:02 IST
UPDATED: SEPTEMBER 04, 2021 19:18 IST

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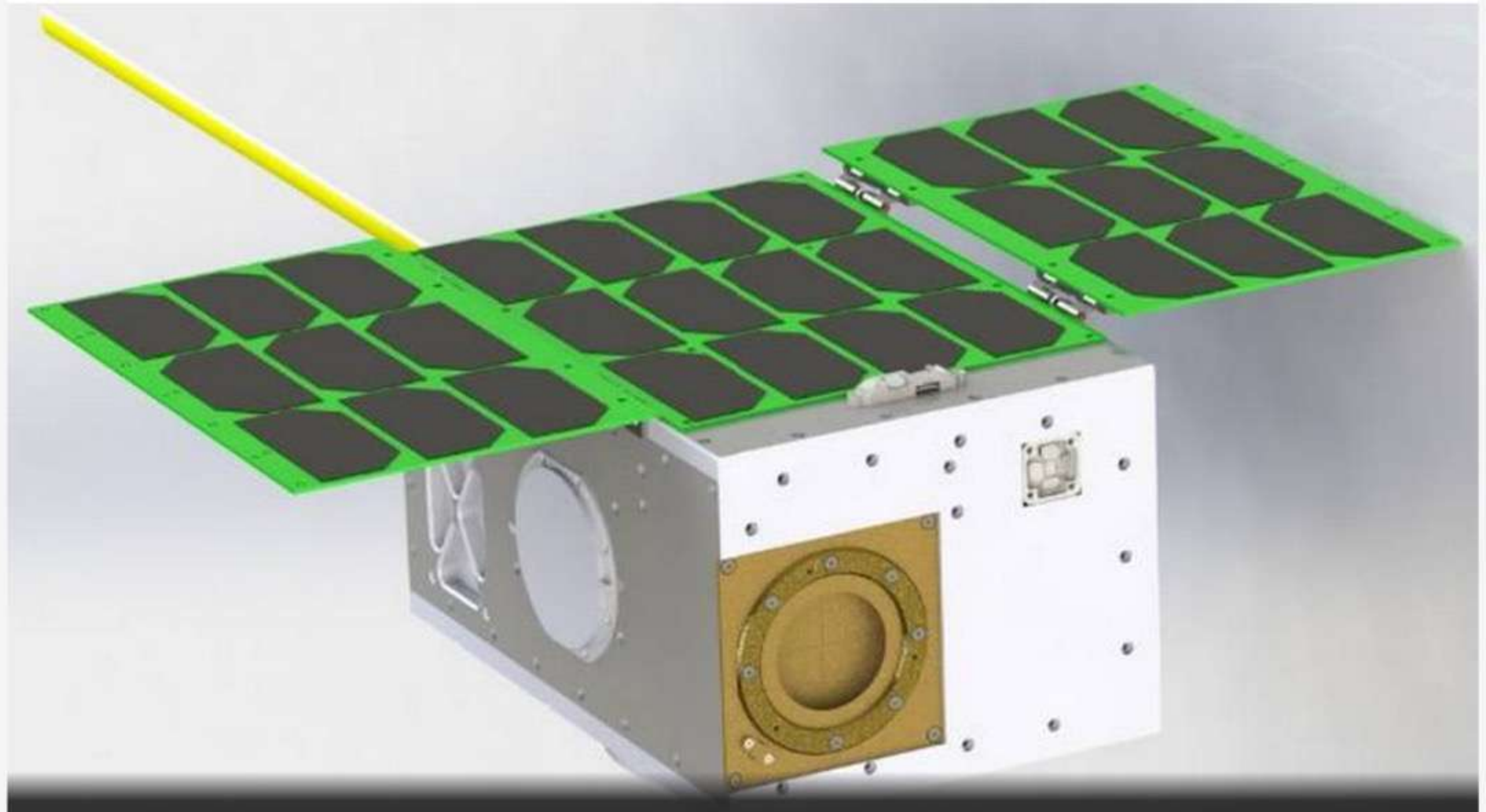
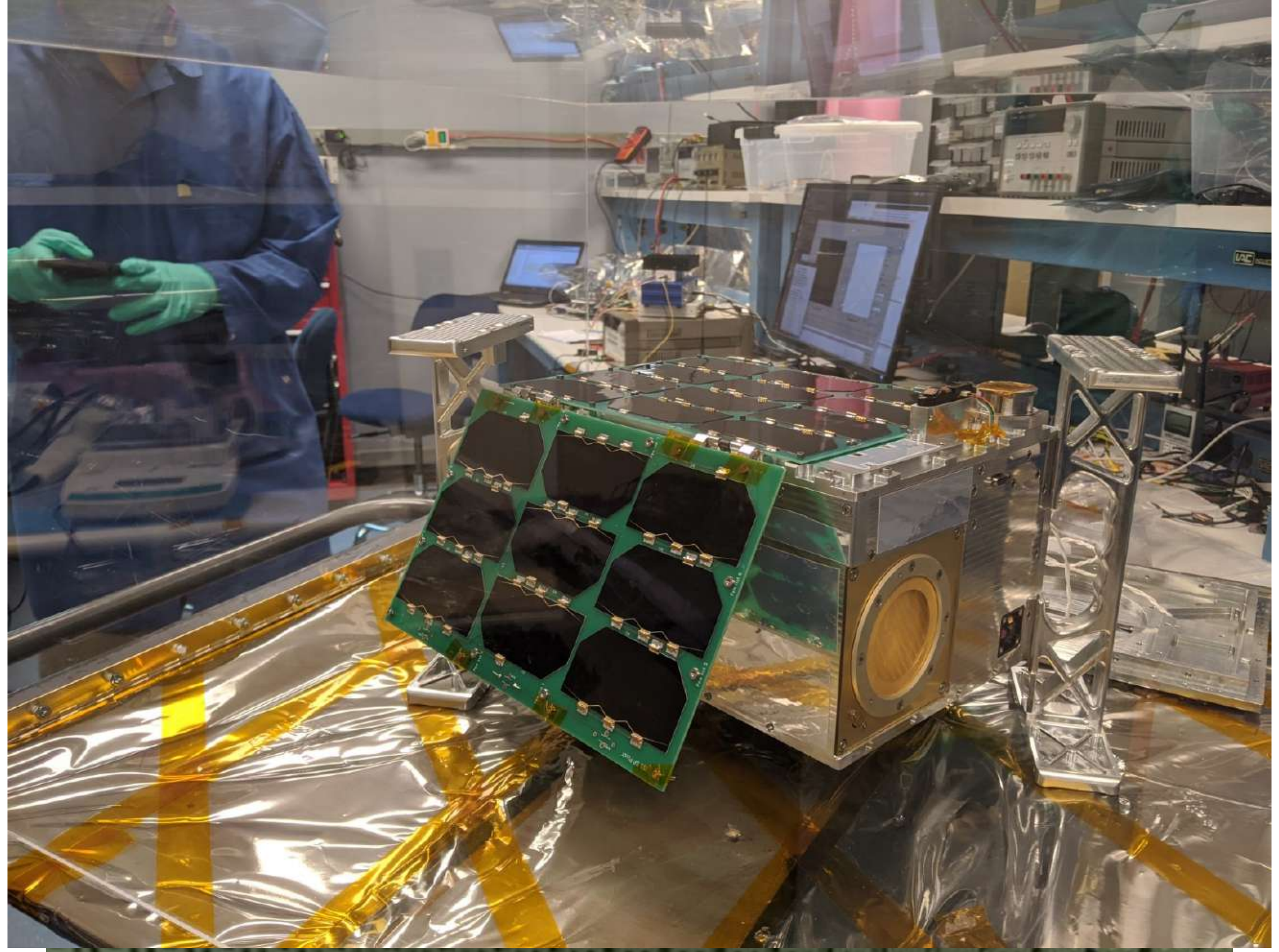
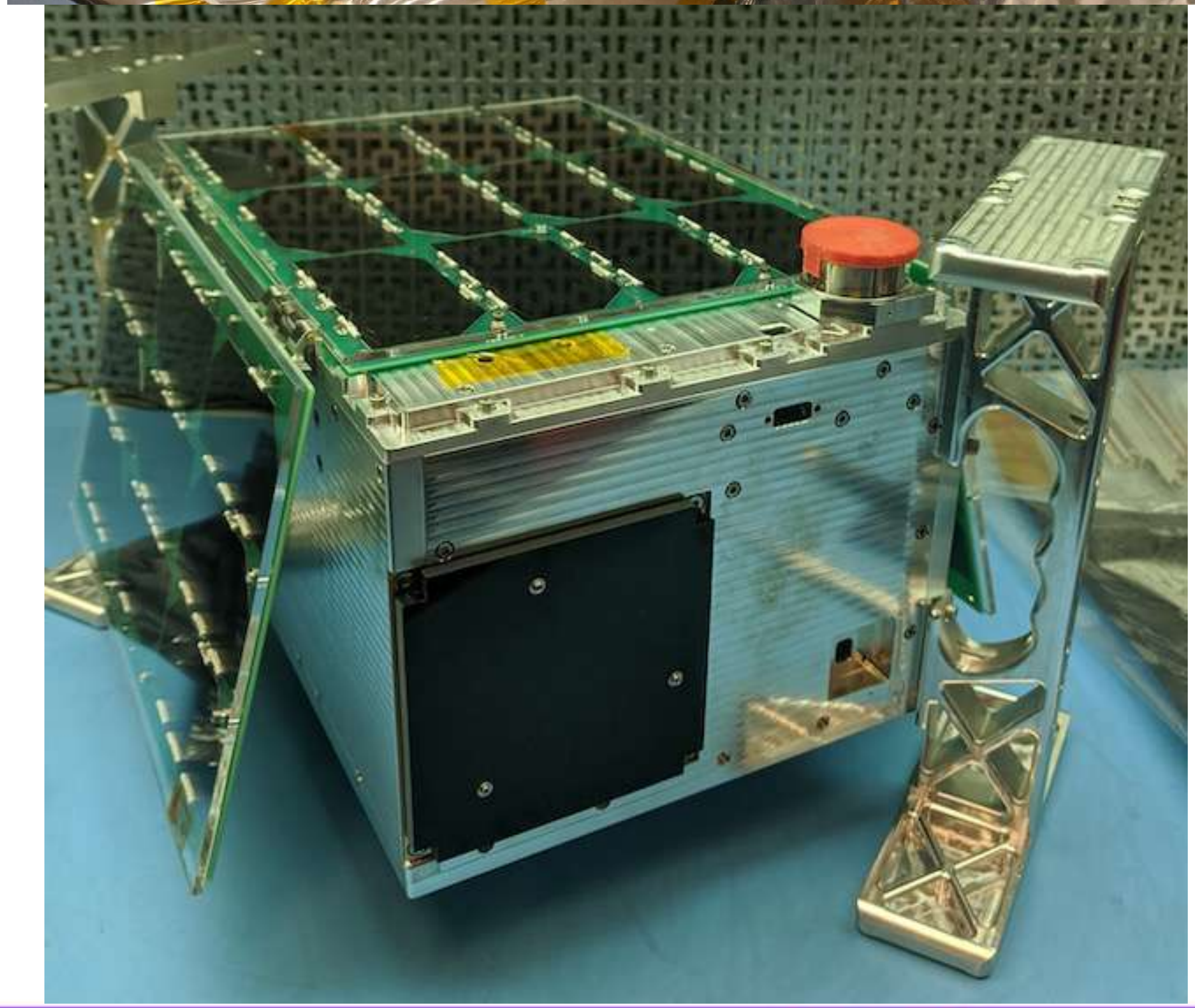


INSPIRESat-1. Photo: lasp.colorado.edu

A collaborative effort by Laboratory for Atmospheric and Space Physics at the University of Colorado Boulder in the US, National Central University, Taiwan, Nanyang Technological University in Singapore and IIST, the small satellite is set to blast off aboard ISRO's upcoming PSLV mission

Trending in Science



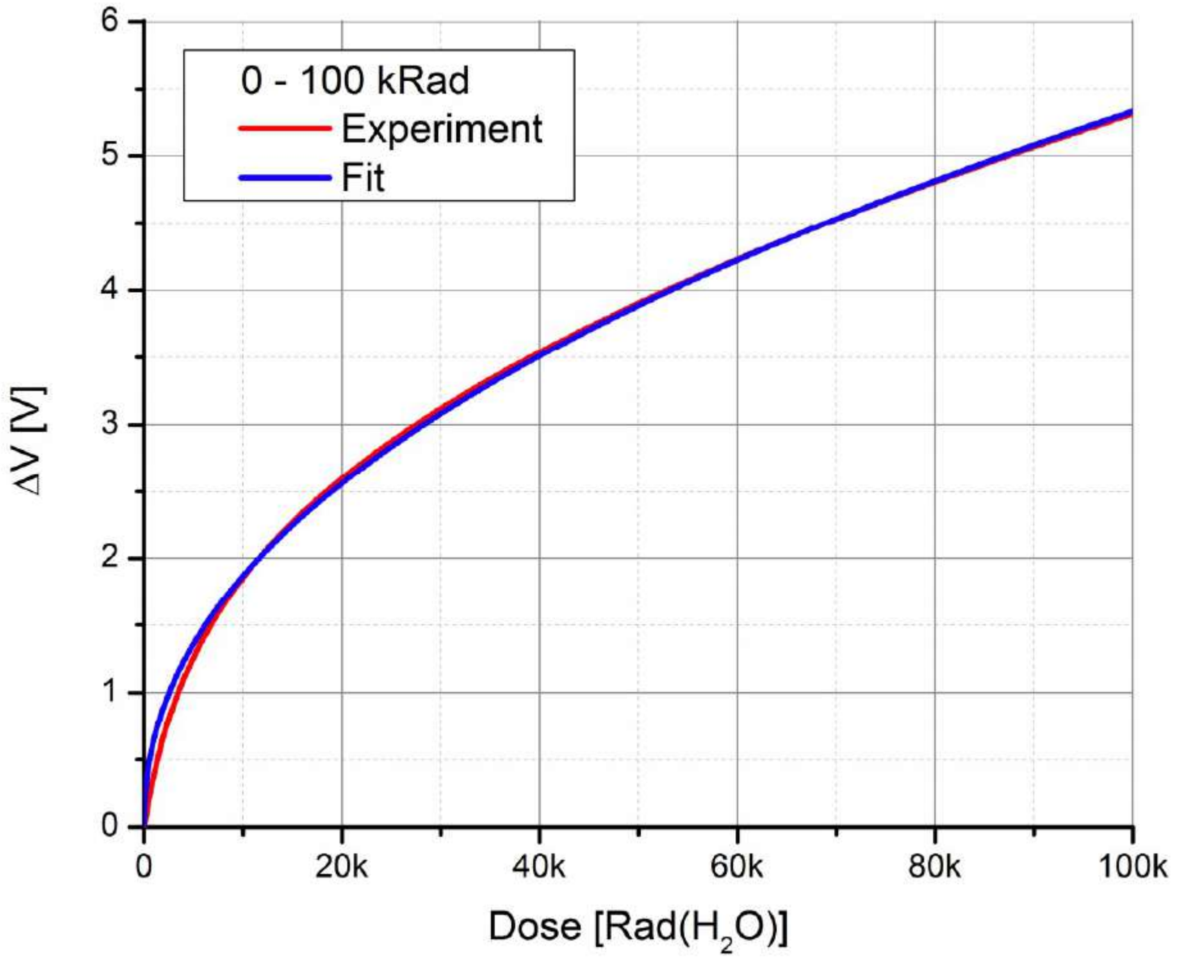


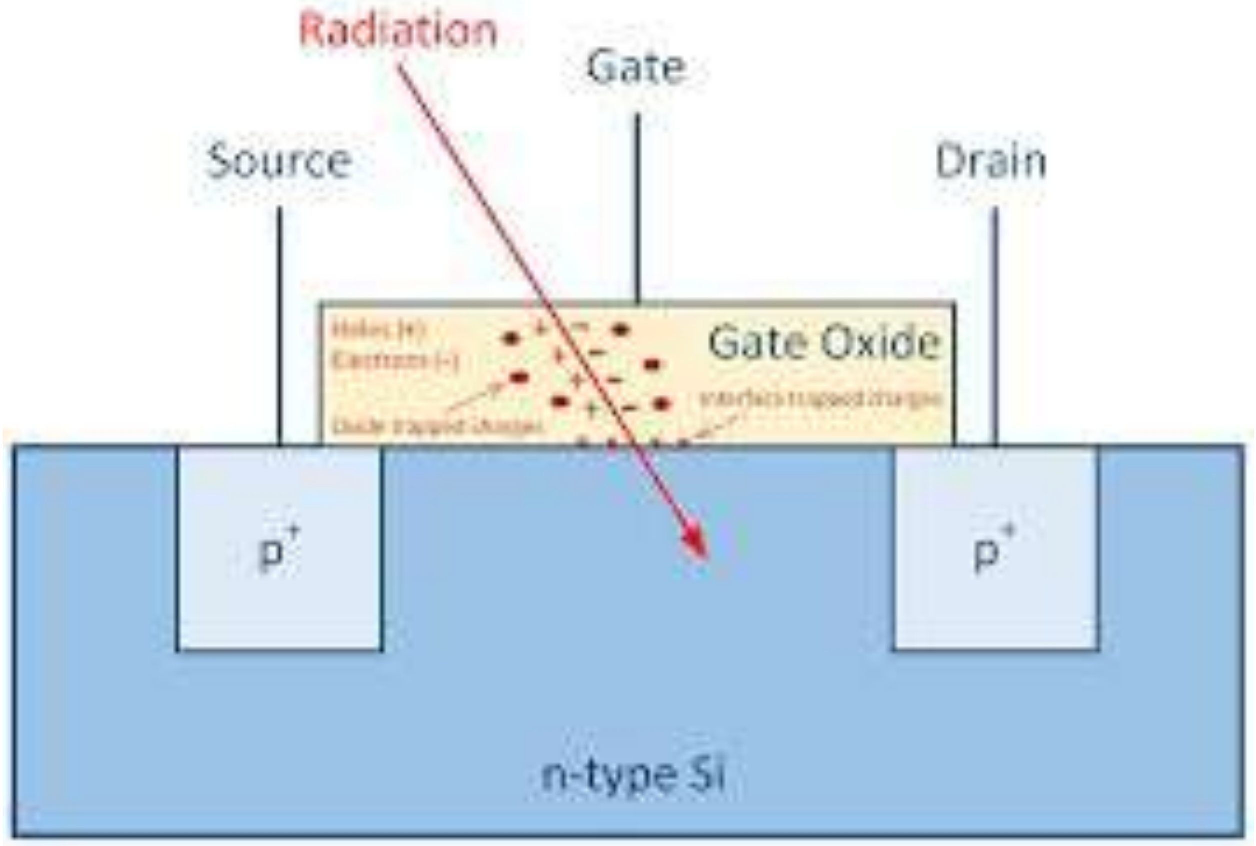
Taiwan’s First Lunar Landing Opportunity

- Partnership with HelioX Cosmos (陽翼先進科技) and SpaceBD to participate in lunar orbiter and landing mission.

- Developing Deep Space Radiation Probe radiation dosimeter payload to measure deep space radiation environment and provide hands-on learning opportunity to students, leveraging IDEASSat avionics development experience.

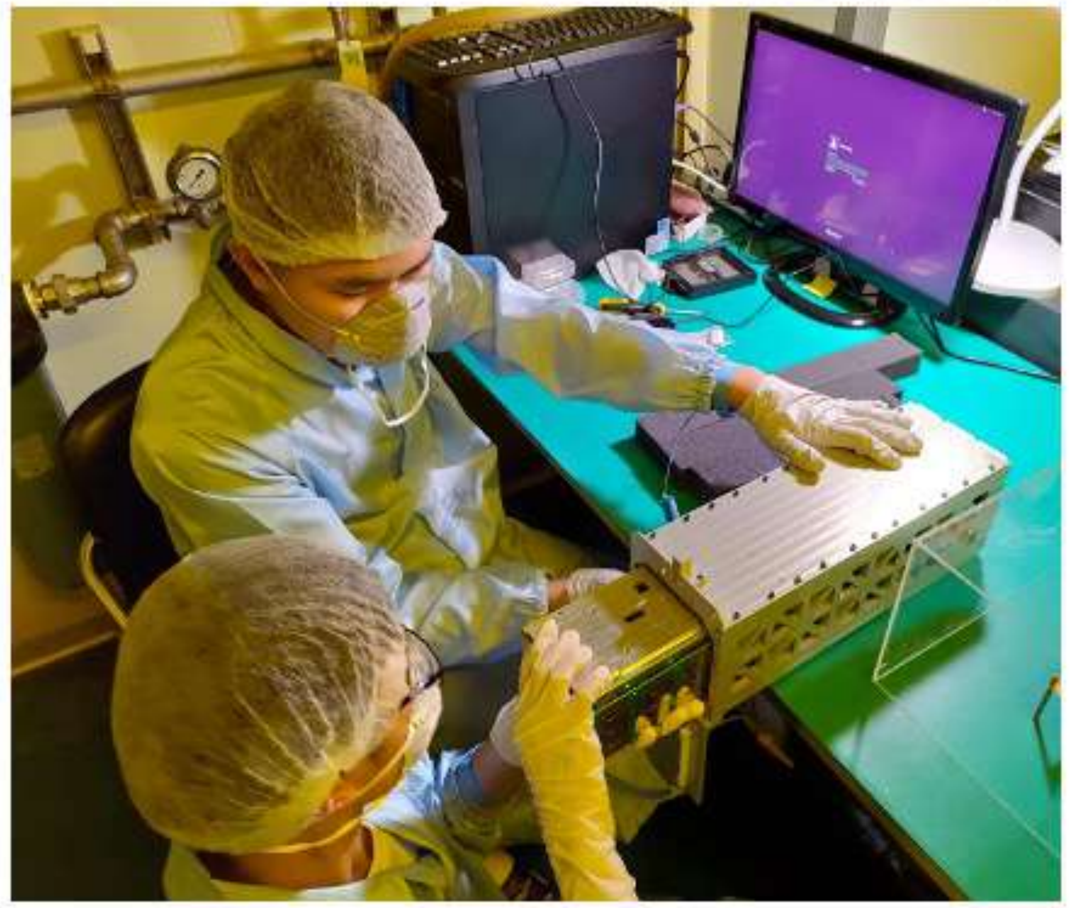
- Launch: 2023 Q4.



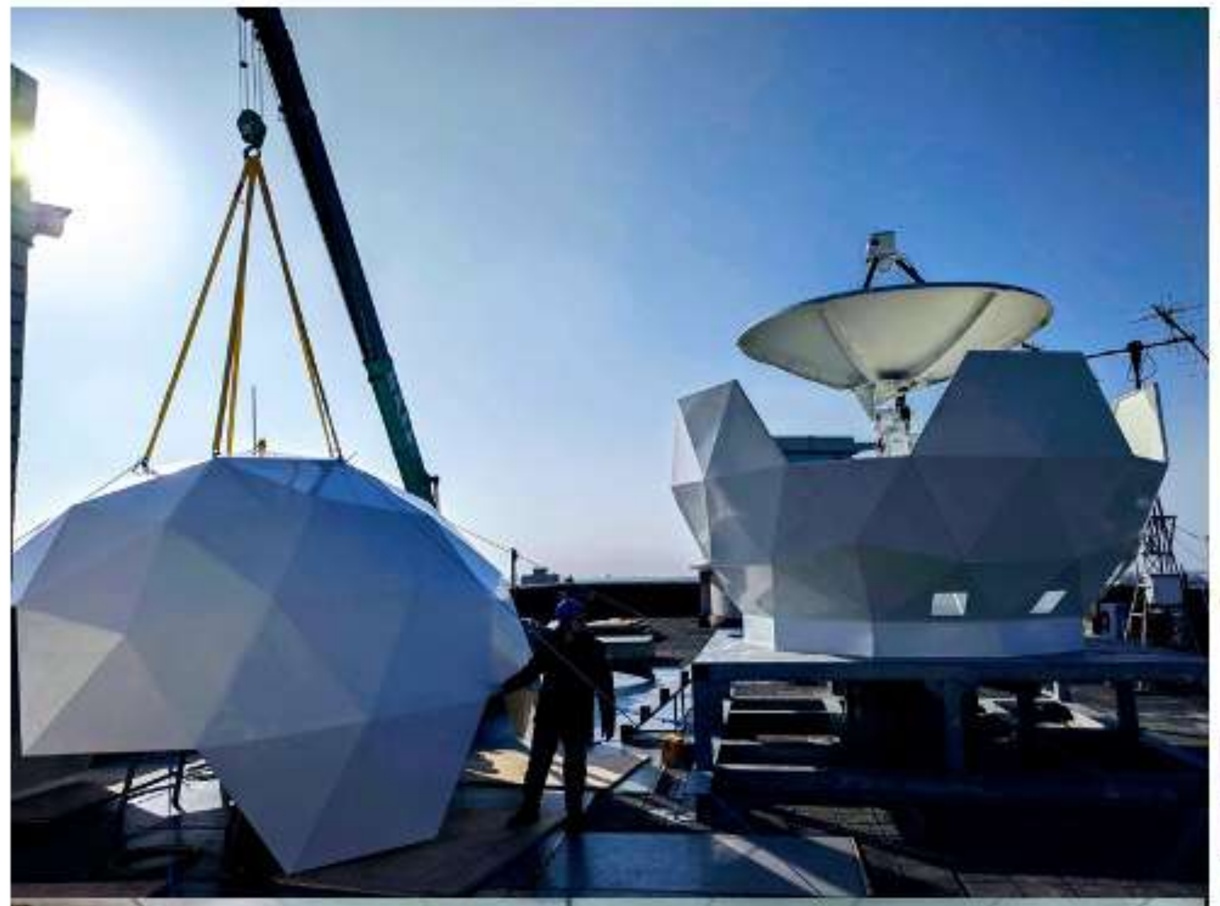


Sponsorships / Joint Development Proposals Welcome!

開拓太空科學應用、開發能力



國際科學衛星群



太空任務飛控

拓展太空產業

太空人才培育

歡迎討論產學合作、技轉、實飛驗證、太空任務共同開發贊助機會！

References

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- JESD57A: Test Procedures for the Measurement of Single-Event Effects in Semiconductor Devices from Heavy Ion Irradiation: https://ntrs.nasa.gov/api/citations/20160014892/downloads/20160014892.pdf?attachment=true
- MIL-STD-1541A, Electromagnetic Compatibility Requirements for Space Systems.
- MIL-STD-883-1 TM1019.9, Test Method Standard for Microcircuits.
- NASA Electronic Parts and Packaging Program: https://nepp.nasa.gov/
- NASA GSFC-STD-7000, GENERAL ENVIRONMENTAL VERIFICATION STANDARD (GEVS) For GSFC Flight Programs and Projects: https://standards.nasa.gov/standard/gsfc/gsfc-std-7000
- NASA MSFC-SPEC-1238, THERMAL VACUUM BAKEOUT SPECIFICATION FOR CONTAMINATION SENSITIVE HARDWARE: https://standards.nasa.gov/standard/msfc/msfc-spec-1238
- NASA/TP—20210021263: State-of-the-Art Small Spacecraft Technology: https://ntrs.nasa.gov/api/citations/20210021263/downloads/2021_SOA_final_508_updated.pdf