KiboCUBE Academy

Live Session #2

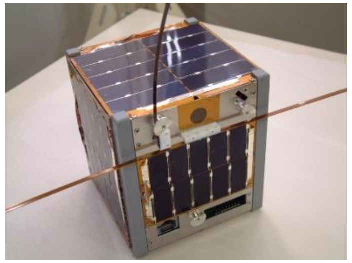
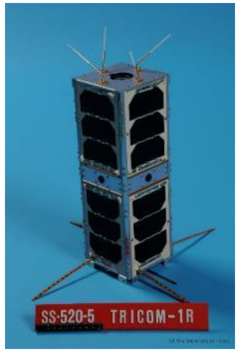
Systems Engineering for Micro/nano/pico-satellites

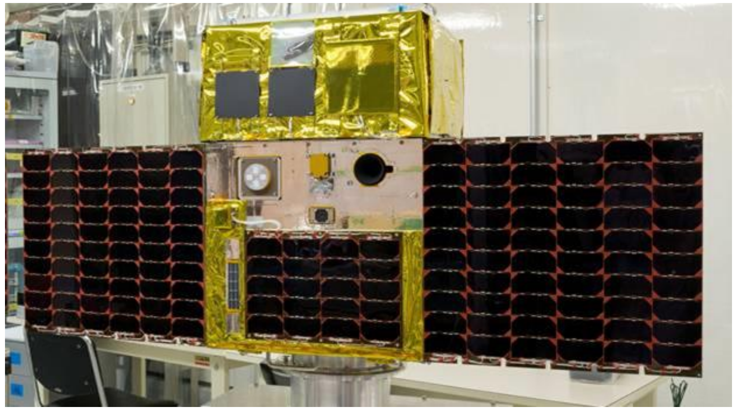
University of Tokyo

Shinichi Nakasuka

This lecture is NOT specifically about KiboCUBE and covers GENERAL engineering topics of space development and utilization for CubeSats.
The specific information and requirements for applying to KiboCUBE can be found at:
https://www.unoosa.org/oosa/en/ourwork/psa/hsti/kibocube.html

Lecturer Introduction



Shinichi Nakasuka, Ph.D.

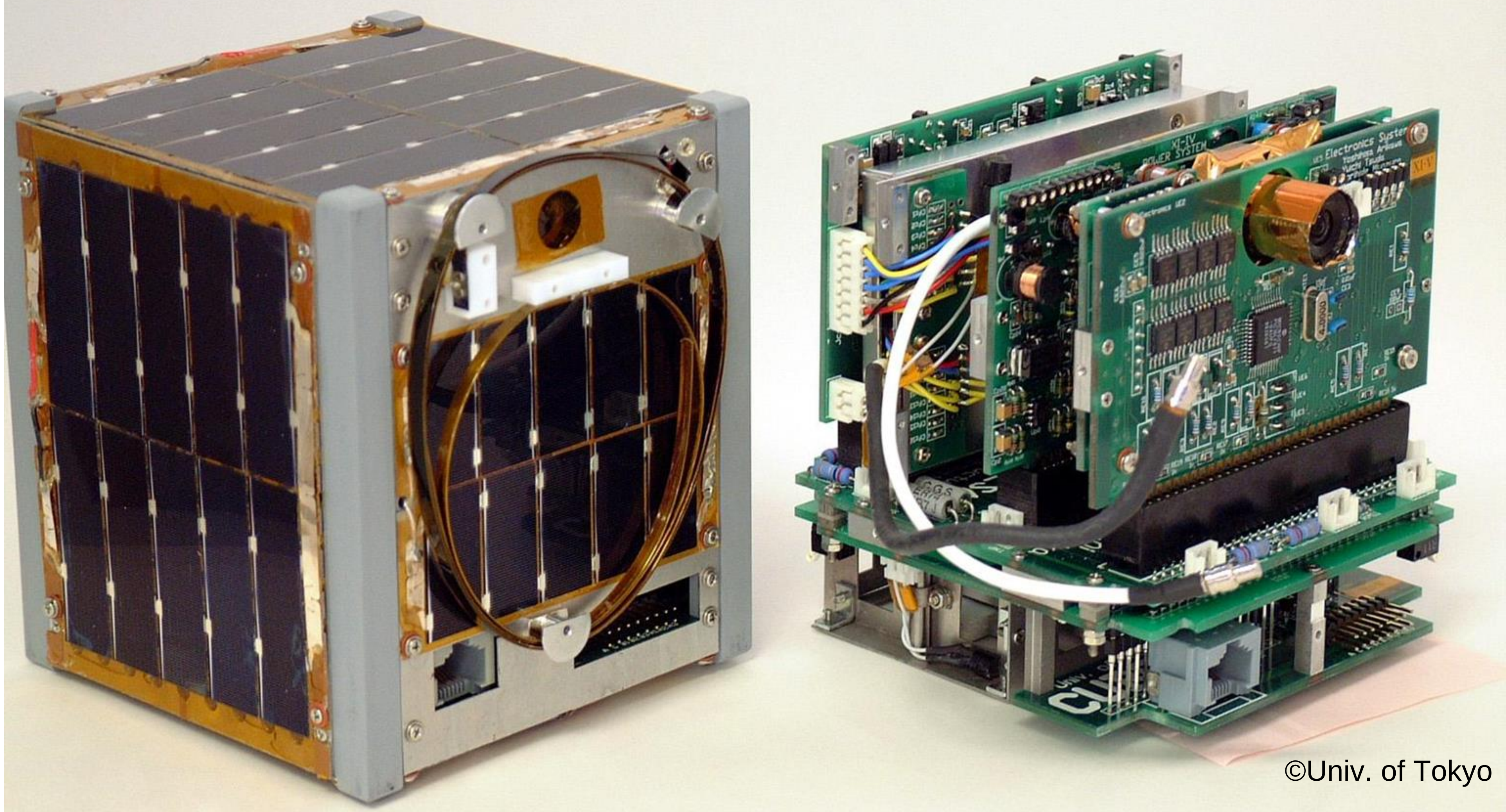
Position:

1990 - Lecturer, Department of Aeronautics and Astronautics, University of Tokyo
1993 - Associate Professor, University of Tokyo
2004 - Professor, University of Tokyo
2012 - Member of Space Policy Committee, Cabinet Office (until 2022)
2013 - Chairperson, UNISEC-GLOBAL

Research Topics:

Micro/nano/pico-satellites, Novel Space Systems, Guidance, Navigation and Control
Autonomy and Intelligence for Space Systems

University of Tokyo's CubeSat Project "XI"



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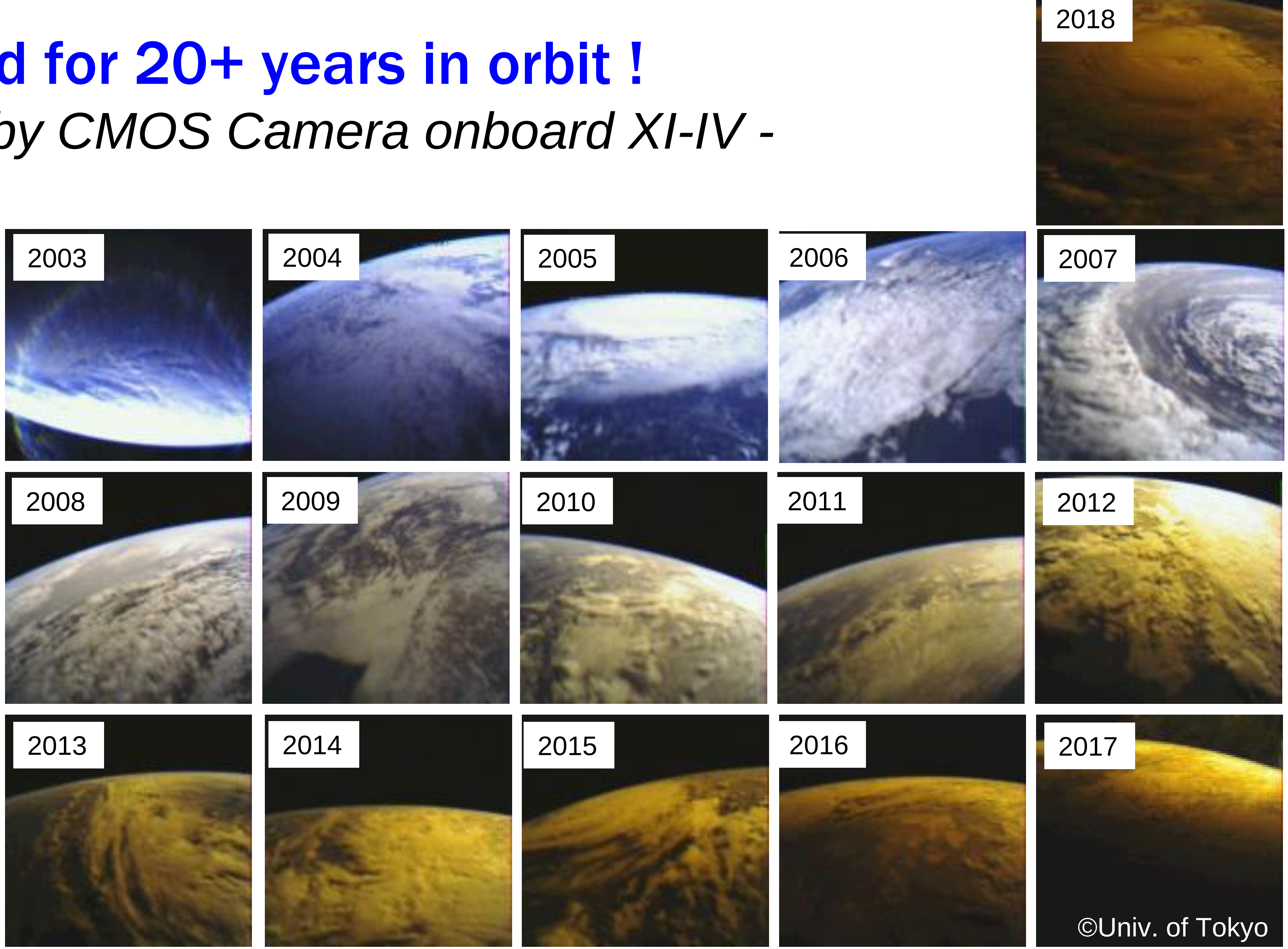
CubeSat "XI-IV" (Launched in June 2003) **"XI-V" (Launched in Oct. 2005)**

Survived for 20+ years in orbit !

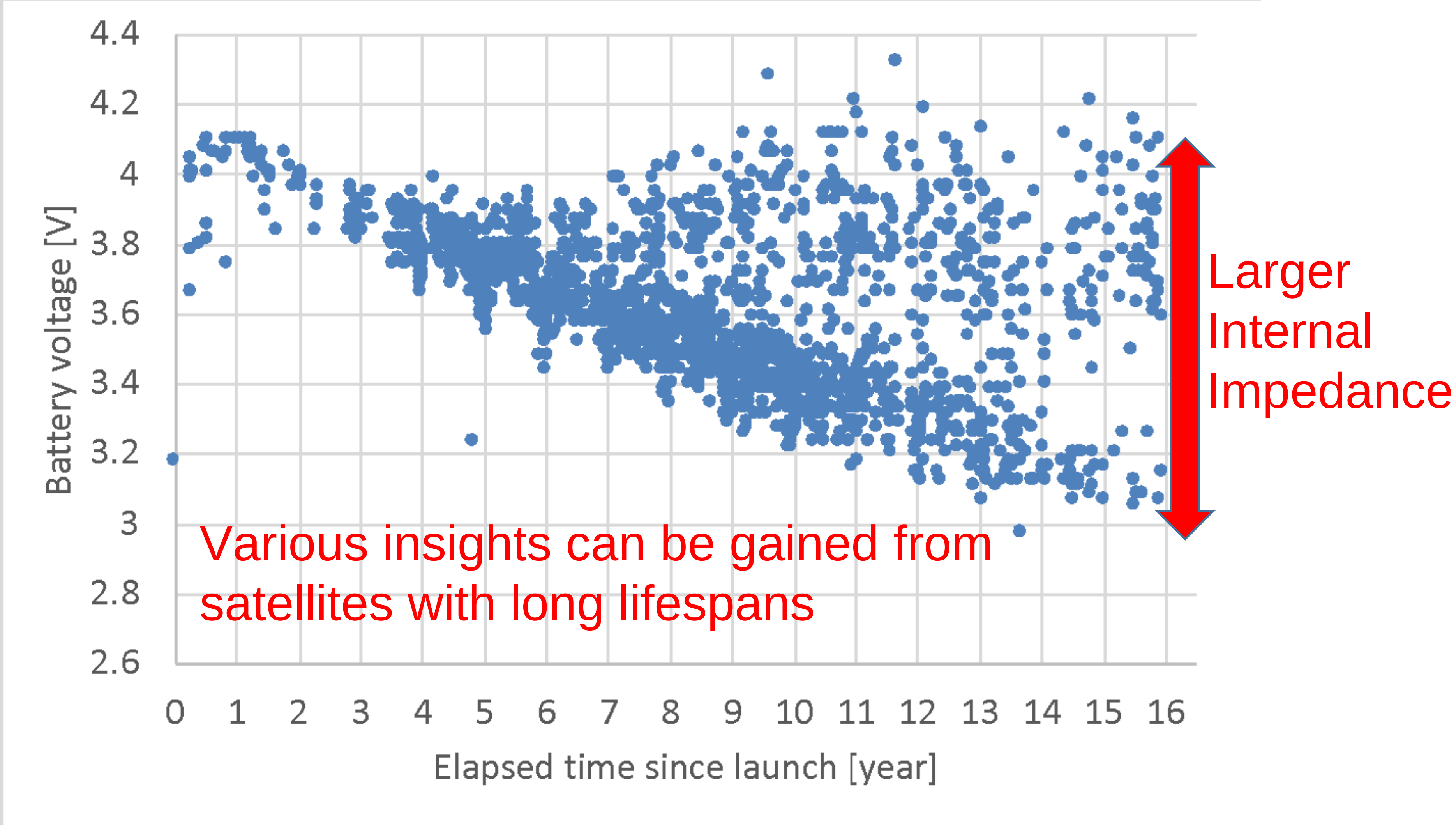
- Image by CMOS Camera onboard XI-IV -

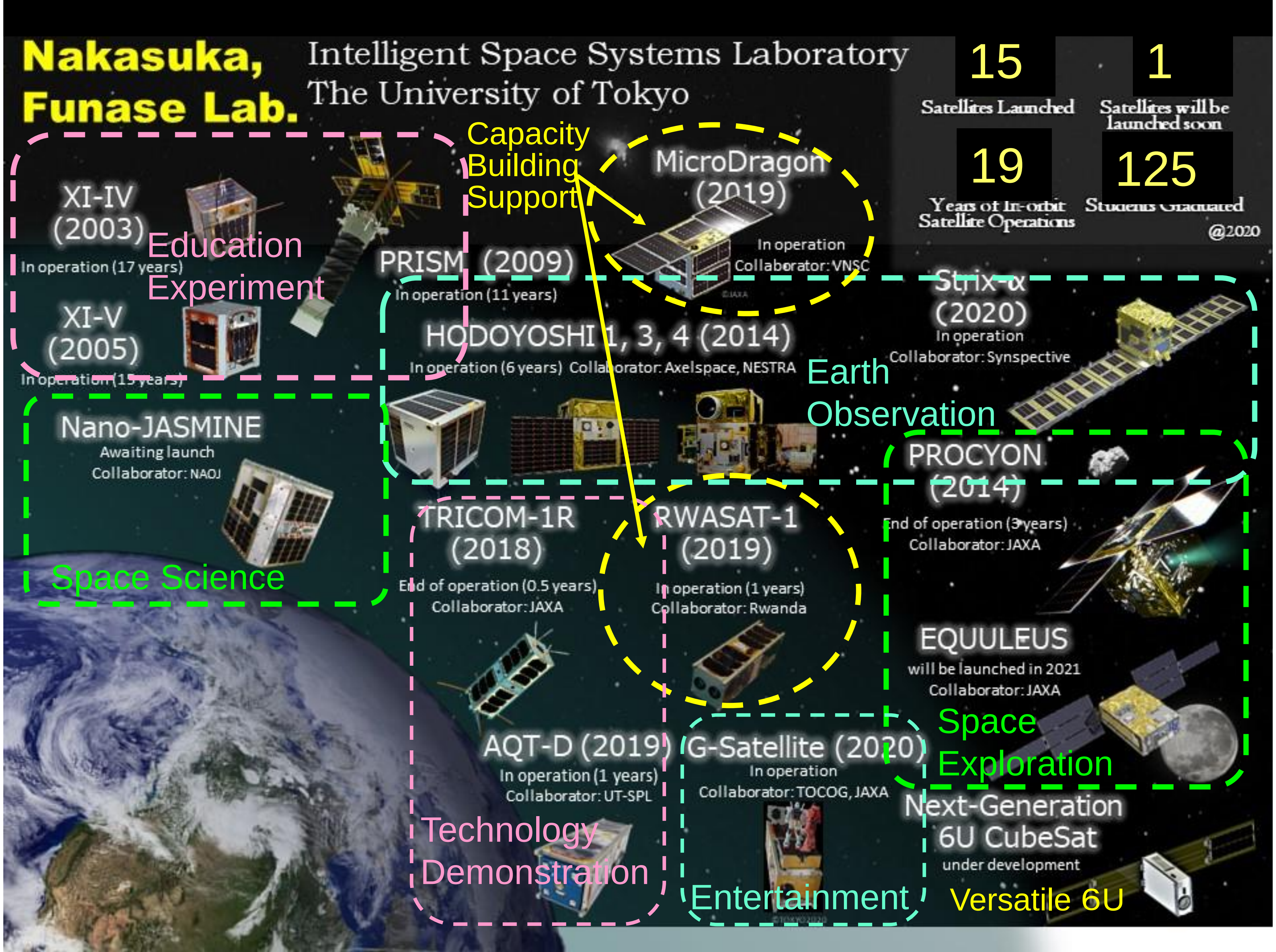


16-year trend in space about Battery

- Li-ion battery voltage history -

If your satellite survives in space for a long time, you can obtain various important information !




Nakasuka, Funase Lab.
Intelligent Space Systems Laboratory
The University of Tokyo
15
Satellites Launched
1
Satellites will be launched soon
19
Years of In-orbit Satellite Operations
125
Students Graduated
@2020
XI-IV (2003)
In operation (17 years)
XI-V (2005)
In operation (15 years)
Education Experiment
Capacity Building Support
MicroDragon (2019)
In operation
Collaborator: VNSC
PRISM (2009)
In operation (11 years)
HODOYOSHI 1, 3, 4 (2014)
In operation (6 years) Collaborator: Axelspace, NESTRA
Strix-α (2020)
In operation
Collaborator: Synspective
Earth Observation
Nano-JASMINE
Awaiting launch
Collaborator: NAOJ
Space Science
PROCYON (2014)
End of operation (3 years)
Collaborator: JAXA
TRICOM-1R (2018)
End of operation (0.5 years)
Collaborator: JAXA
RWASAT-1 (2019)
In operation (1 years)
Collaborator: Rwanda
EQUULEUS
will be launched in 2021
Collaborator: JAXA
Space Exploration
AQT-D (2019)
In operation (1 years)
Collaborator: UT-SPL
G-Satellite (2020)
In operation
Collaborator: TOCOG, JAXA
Next-Generation 6U CubeSat
under development
Technology Demonstration
Entertainment
Versatile 6U

Hodoyoshi-3,4 (Earth Observation Satellites Launched in 2014)

Low cost and affordable micro-satellites (50-60kg) to be developed within $3M and 2 years

Size:50x50x80cm 60kg Downlink: 10-20Mbps Power: max 100W average 50W

<u>Attitude Control Capability:</u>

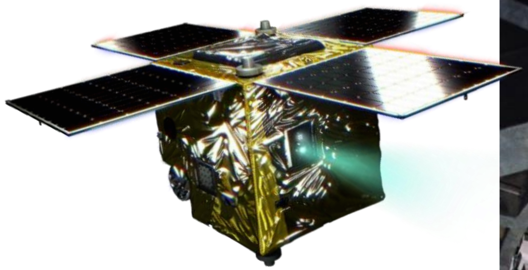
- Stability	0.08 deg/s (Roll, Pitch)	0.8 deg/s (Yaw)
- Pointing accuracy	0.2 deg	2 deg
- Determination accuracy	0.0048 deg	0.048 deg

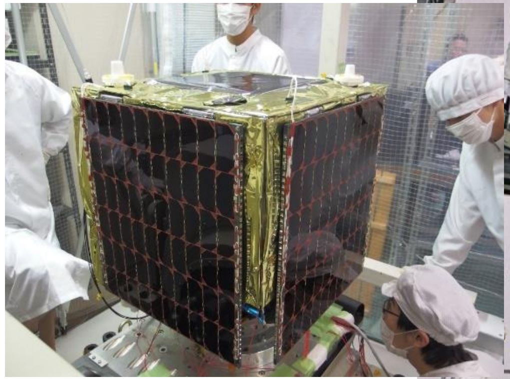
Wide Angle Camera

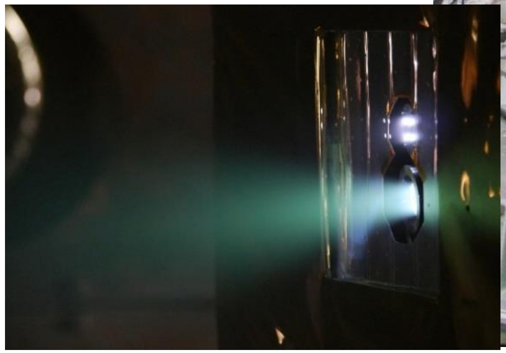
Chiba
（6m GSD Camera)

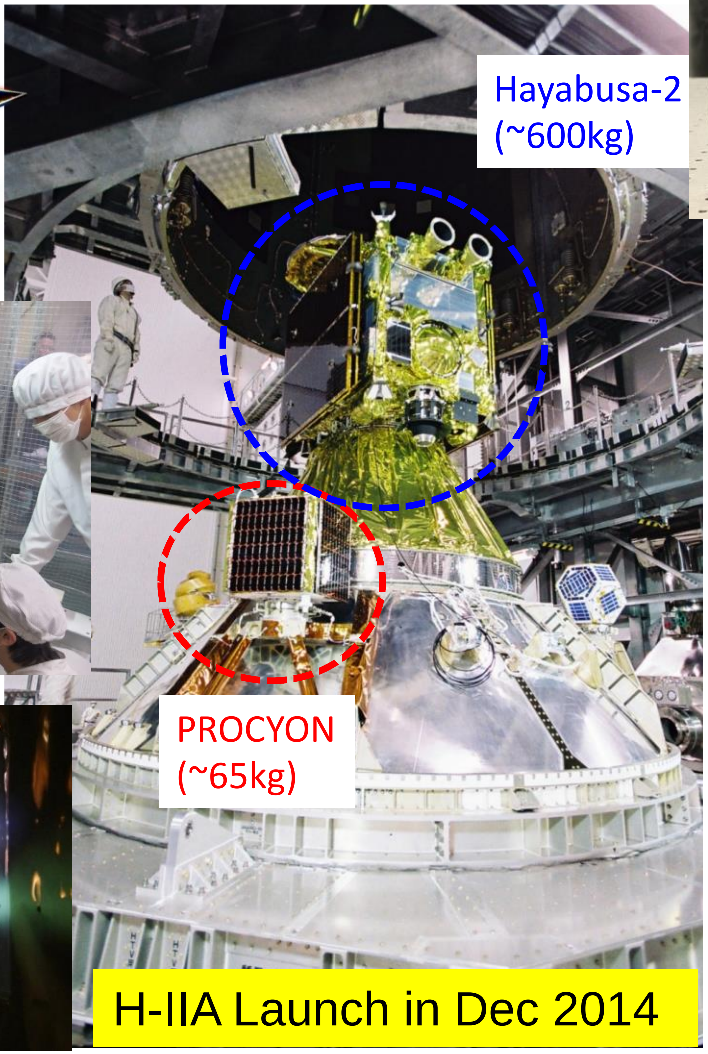
PROCYON (World first 50kg class deep space probe)

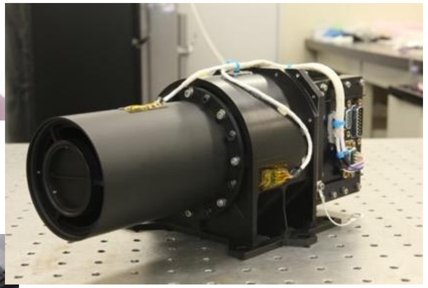
- The World First Interplanetary Micro-sat (65kg)
- Joint project with JAXA





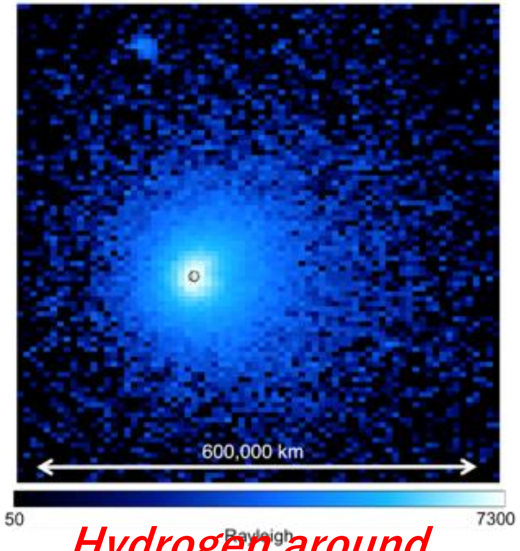




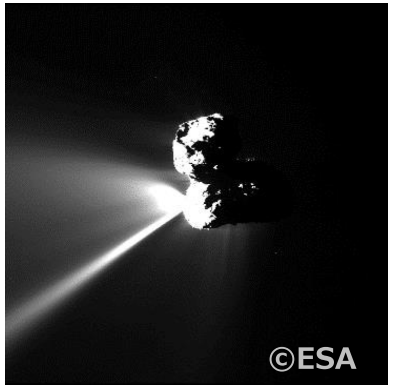


LAICA
(Hydrogen imager)

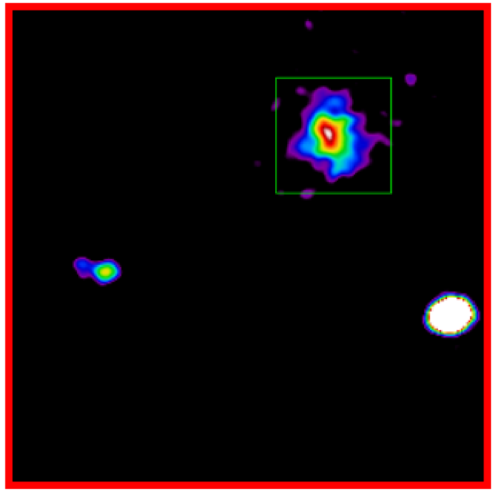
Earth's hydrogen corona



Kameda et al., 2017 GRL



Hydrogen around 67P/Churyumov-Gerasimenko

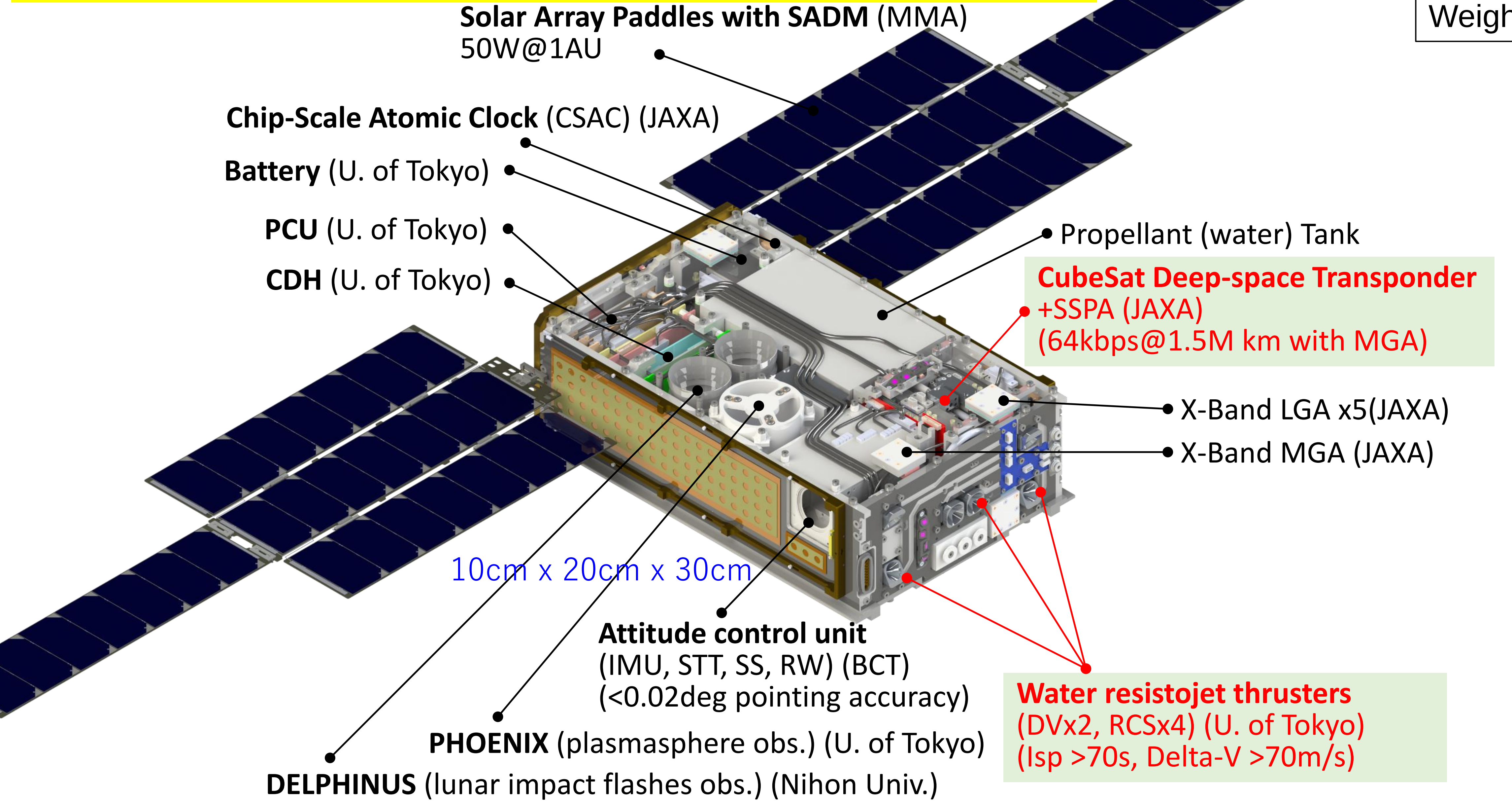


Shinnaka et al., 2017 AJ

Quick (<14 months) development achieved

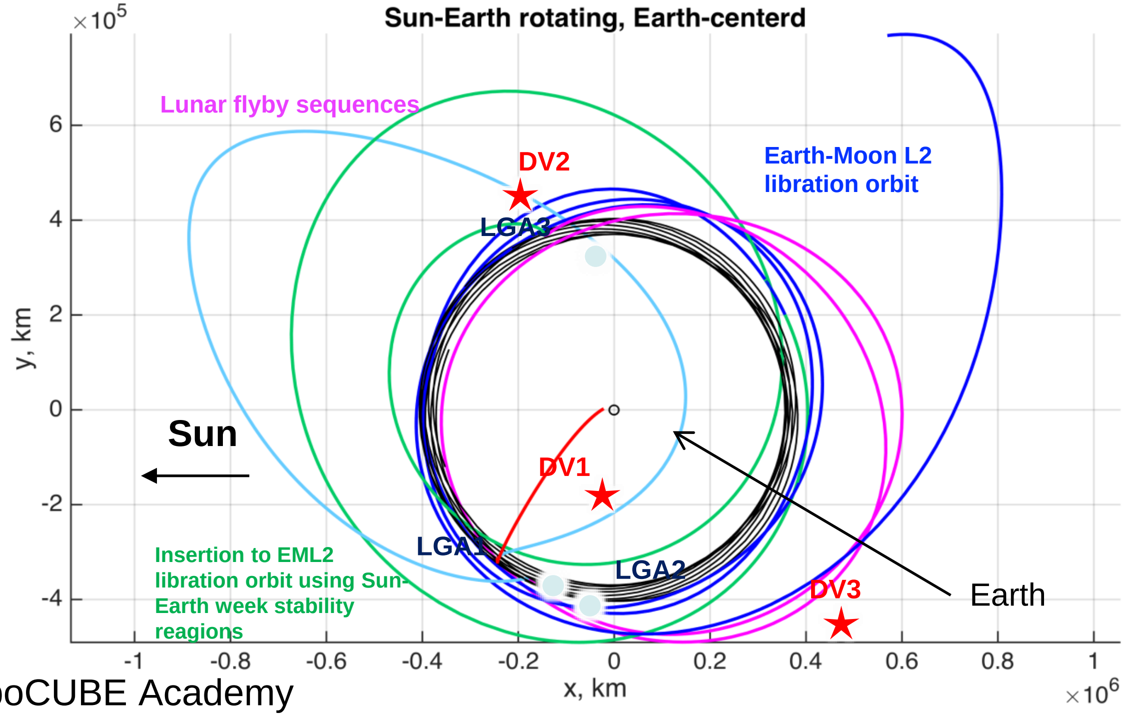
EQUULEUS Project: Space Exploration mission can be realized with just 10kg class satellites !

Size: 6U
Weight: 11kg



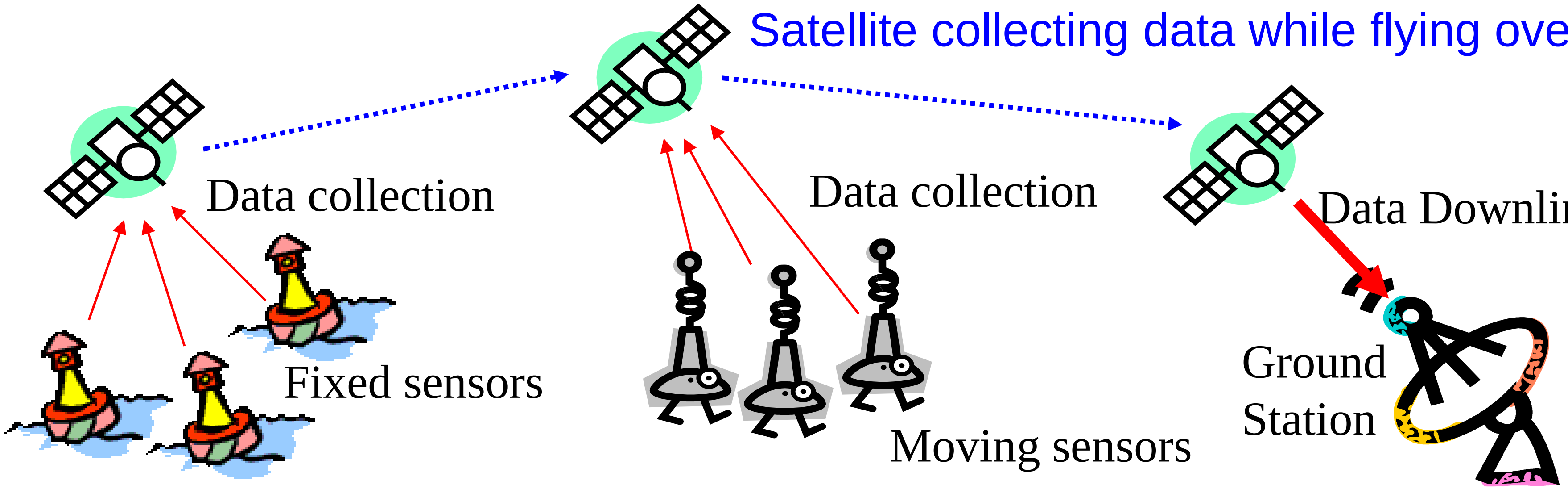
2022.11.22 Moon as seen from 5550km alt

Launched by Artemis-1 on Nov 16, 2022, flying towards EML2



KiboCUBE Academy

“Store & Forward” collects ground information

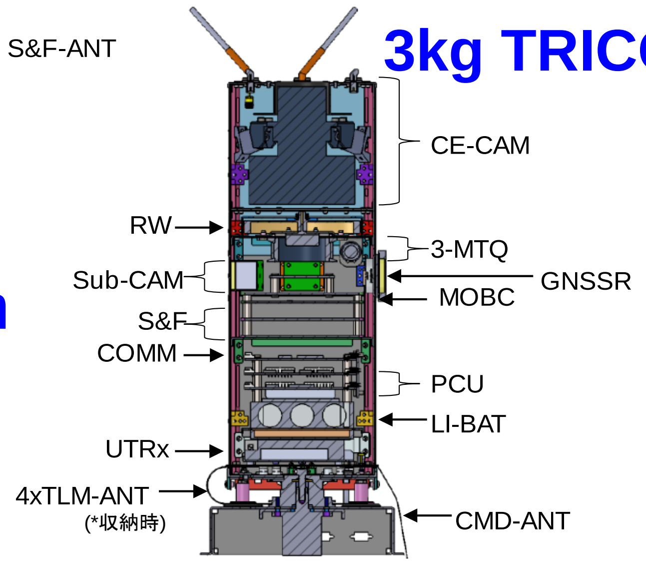


Application areas: disaster prediction,
water level monitoring, soil moisture, PH…..

Key Issue: **<u>How to send data with very low RF power to the satellite ?</u>**

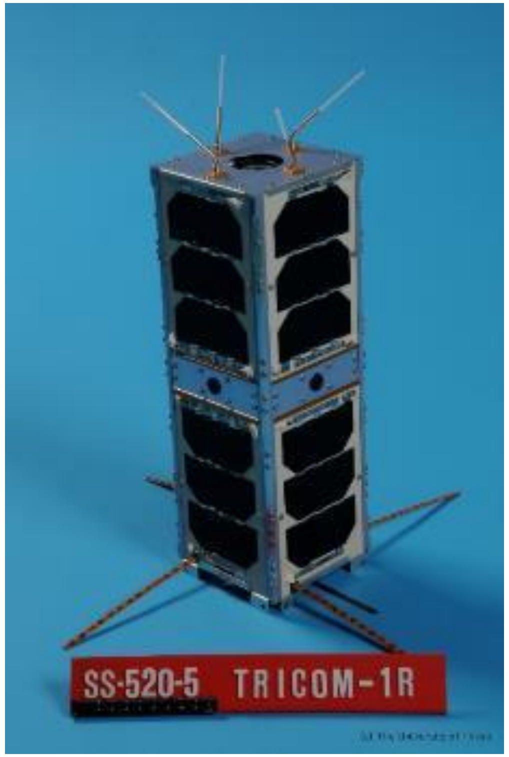
IoT communication

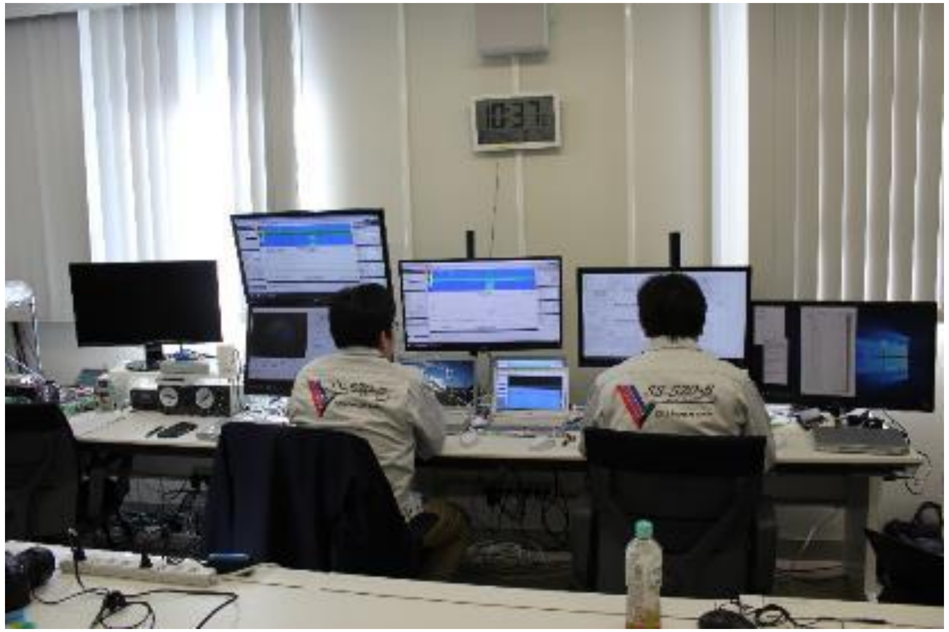
8mW low RF power, low data rate (300bps) transmission is tested in TRICOM-1R.



Launch of TRICOM-1R by SS-520-5

- Launched on Feb.2018 by the world smallest orbital rocket by JAXA/ISAS
- S&F and camera experiments successful
  - **<u>8-130mW transmission from Japan, RWANDA Malaysia, Chille, etc. succeeded</u>**
- International Network of S&F is now being discussed

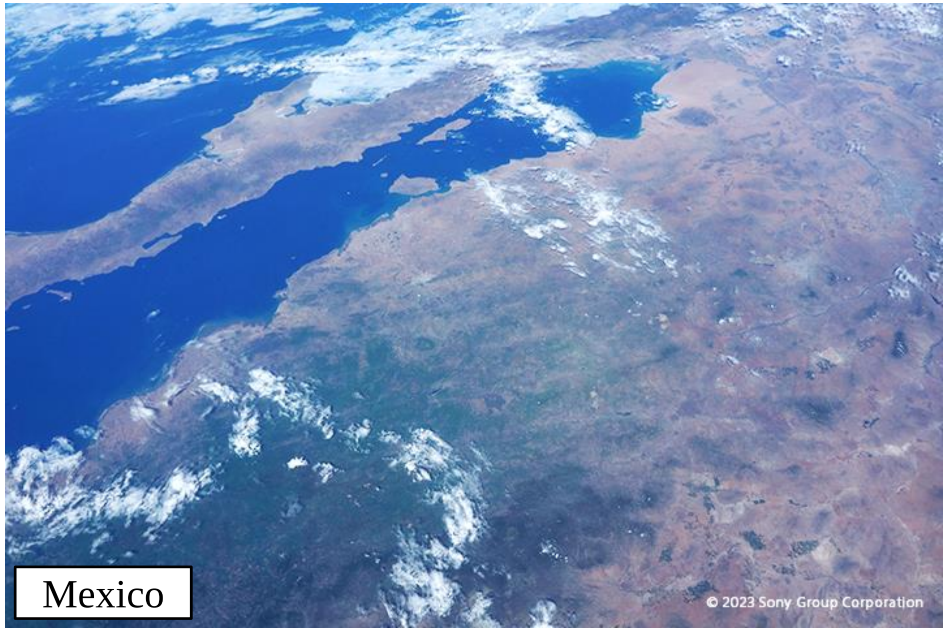


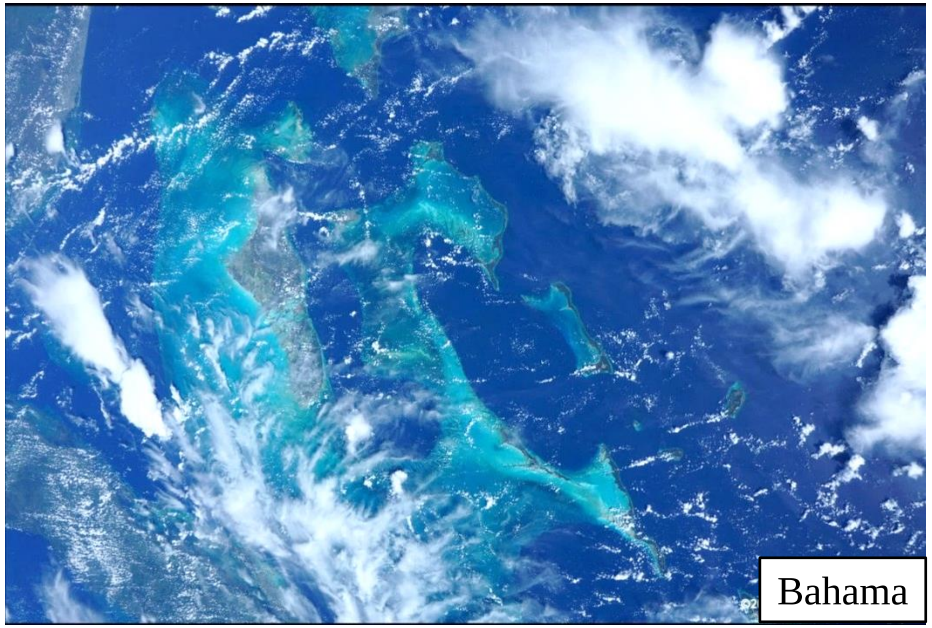


SONY “Sphere-1 Eye”

- Collaborative Project by SONY, JAXA, University of Tokyo
  - University of Tokyo developed 6U bus and conducted total system integration, and now is operation this satellite (good for stundet education !)
- Mission: SONY wants customers to operate satellite directly to capture various images (such as Earth, star, etc.)
- Developed within 2.5 years and launched on January 3, 2023

Captured Images by Sphere-1 Eye



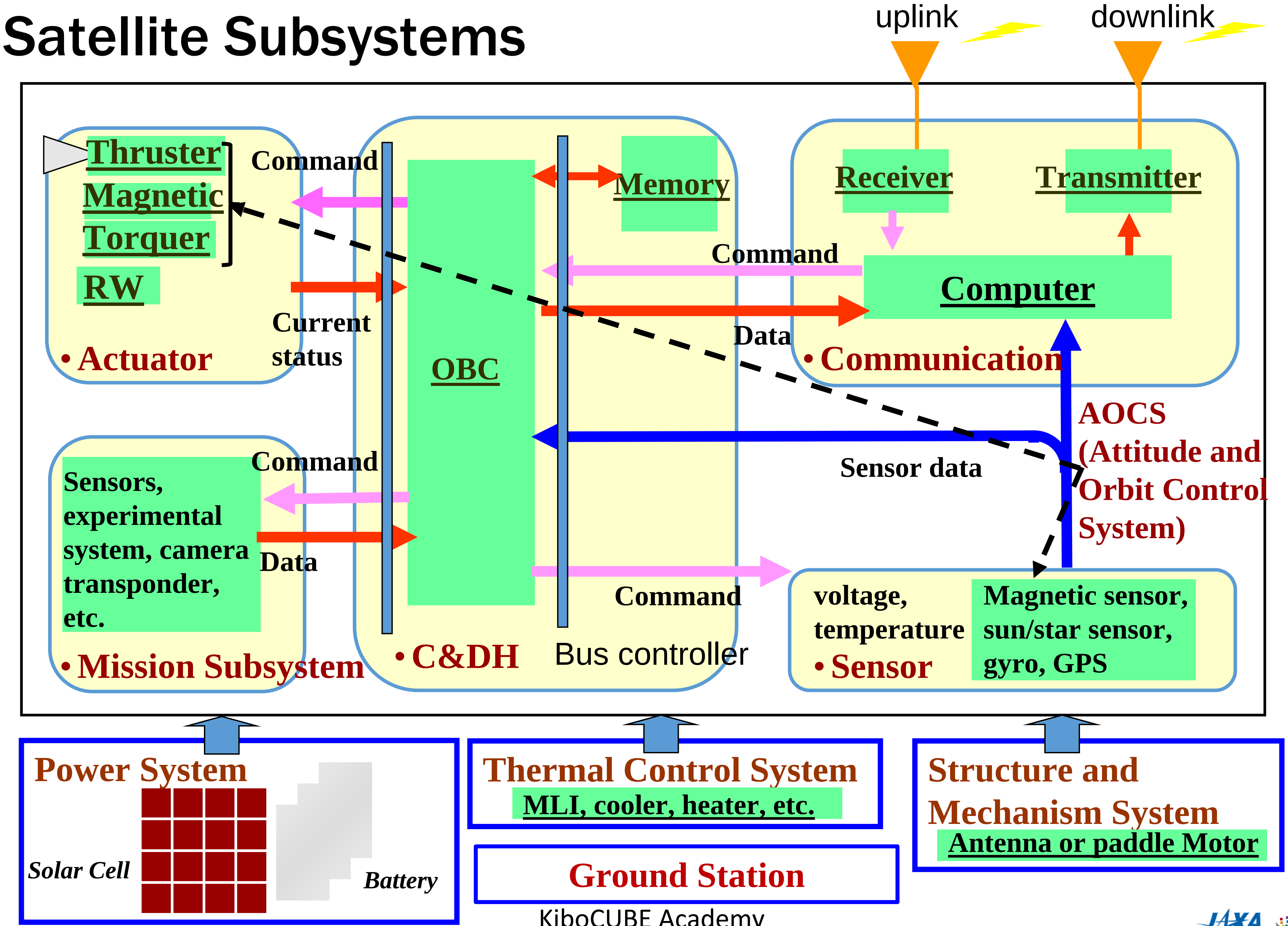


Contents

Systems Engineering for Micro/nano/pico-satellites

1. Subsystems and their Relationships

Typical Satellite Subsystems



Relationships between Subsystems

You should design subsystem interfaces properly.

Top level design will decide satellite architecture

- How many and what kind of CPUs are to be used?
  - One or two OBCs for main functions and attitude control, or more?
- Between C&DH and other subsystems
  - Information line: RS-232C, RS-422, MIL-STD-1553B, SpaceWire, CAN bus, ----
  - Interval of data exchange and amount of data to be transferred
  - What kind of data to be transferred (house keeping / mission data)
- Between C&DH and communication subsystem
  - How will large volumes of data for downlink be stored?
- Between C&DH and mission subsystem
  - How will mission components be controlled and how are those data received?
- Between power subsystem and other subsystems
  - What kind of reset (power off-on) function is to be implemented?

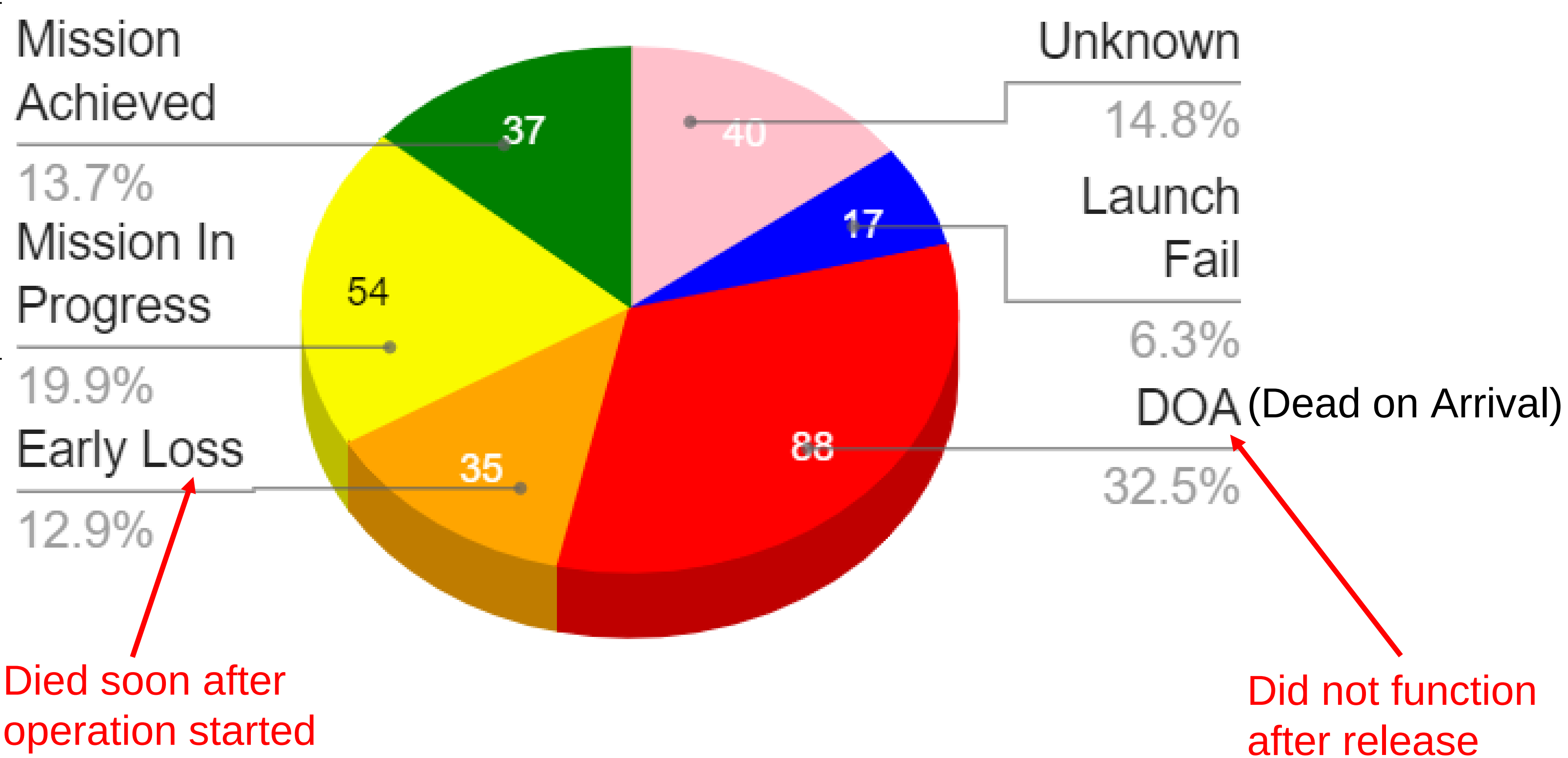
2. Possible Causes of CubeSat Failures

Past Failures of CubeSat

Failure rate is still about 50%

CubeSat Mission Status, 2000-present (271 spacecraft)

Successful mission is only 35%



Based on Study by St. Louis Univ.
https://sites.google.com/a/slu.edu/swartwout/cubesat-database

Frequent Causes of Failure and Countermeasures

What should you take special care of?

- Radiation causes electronics failures
  - ✓ Use space-proven parts or conduct radiation tests during early development phases
- Electric power subsystem fails to provide power, or battery voltage gets very low and cannot be recovered
  - ✓ Design satellite behaviors under low battery voltage
  - ✓ Make solar power generation possible in any situation
- Communication subsystem fails to communicate with the ground station because of component failures, insufficient RF power or EMI (Electromagnetic Interference)…
  - ✓ Implement backup systems (redundant receivers, etc.)
  - ✓ Calculate the link equation correctly and add enough link margin
  - ✓ Conduct ground tests using EM or FM in a realistic situation
  - ✓ Find and consult with communication technology experts

3. Why Space Systems are Difficult ?

Why space system is difficult?

- Harsh Space Environment -

■ Vacuum	Vaporization, cold welding, friction, electric discharge, change of material, heat spot….
■Radiation	Electronics parts malfunction and breakdown, degradation of solar cells and materials…..
■Thermal	Large temperature differences/cycles, heat shock, heat spot…..
■Launch	Vibration, shock, acceleration, sound vibration…..
■Distance	Long range communication over 500-2000 km…..

Others: Atomic Oxygen, Plasma, Debris/Meteoroids, Ultraviolet rays

“Non-maintainable System”

Once launched, you cannot touch your satellite. Then what should you do?

- A satellite cannot be touched until the end of its life once it is launched.:

  called “non-maintainable system”

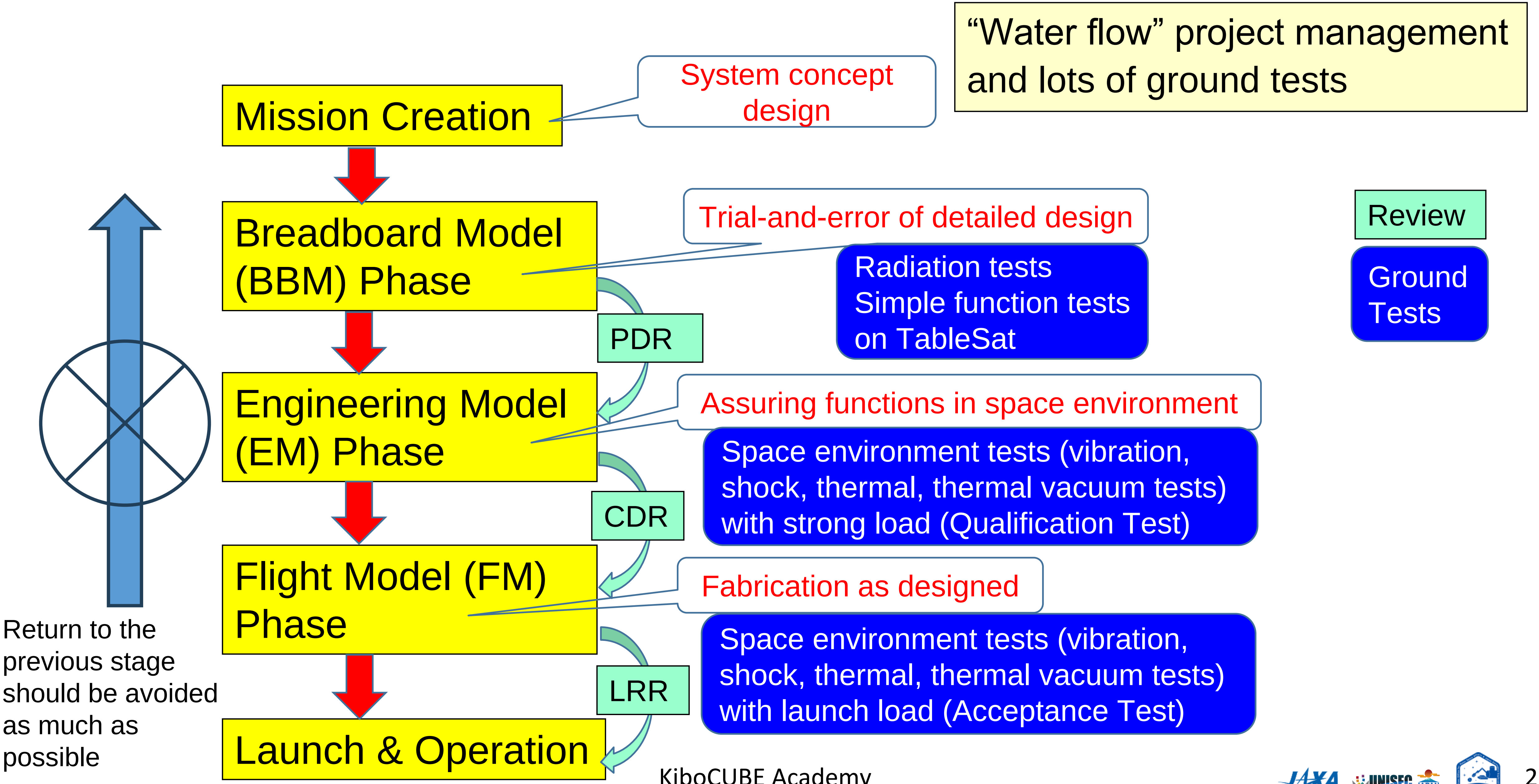
- Sometimes a satellite has to survive in space for more than 10 years without any human interactions. Therefore……

- Imagine all the possible events and anomalies which may happen to your satellite and prepare countermeasures for them. Imagination is very important !

- Conduct ground tests in various settings to ensure proper functioning of your satellite in the space environment, in various operation modes.

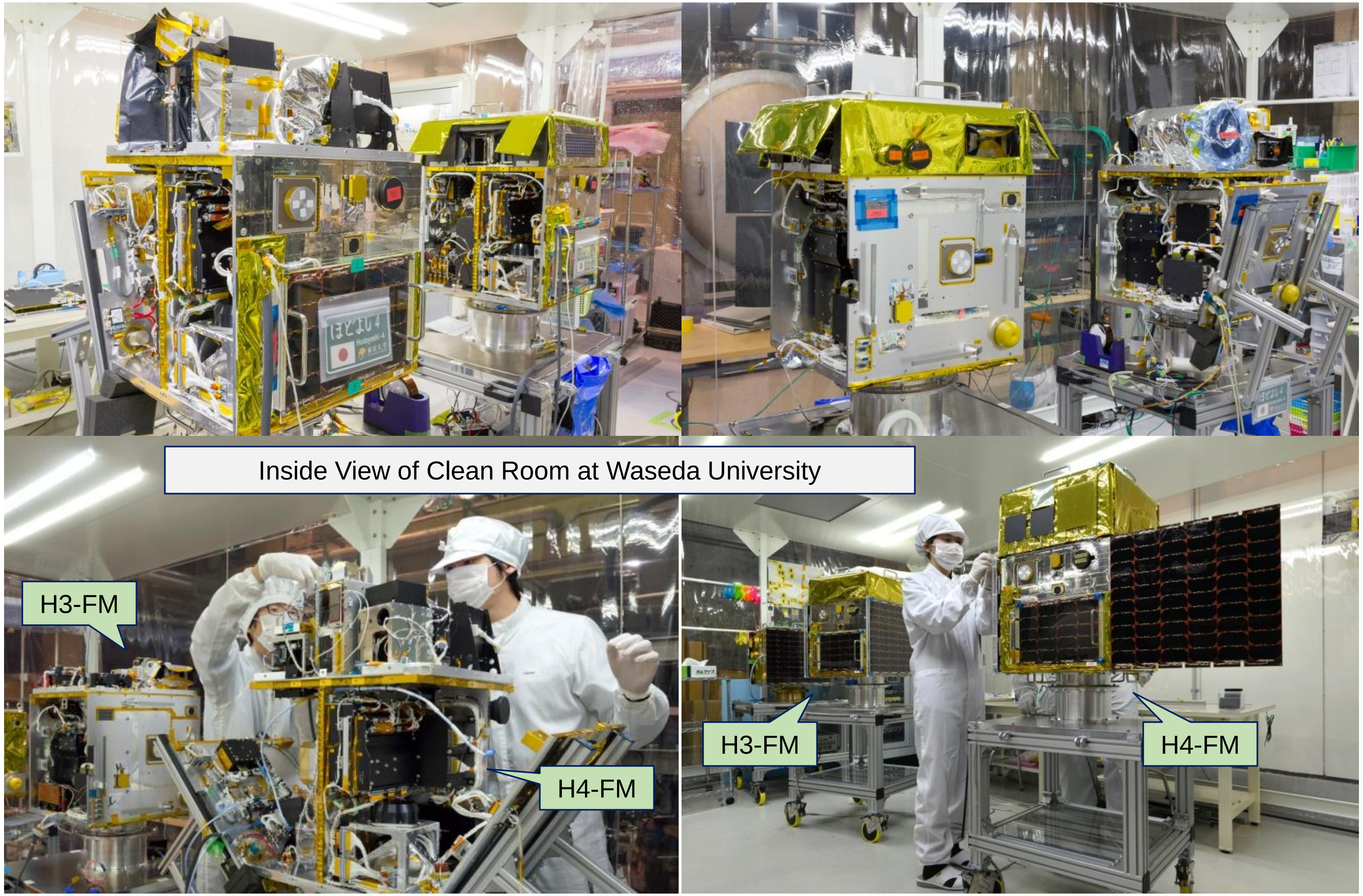
4. Make Your Satellite “Die Hard” !

Water Flow Type Project Management

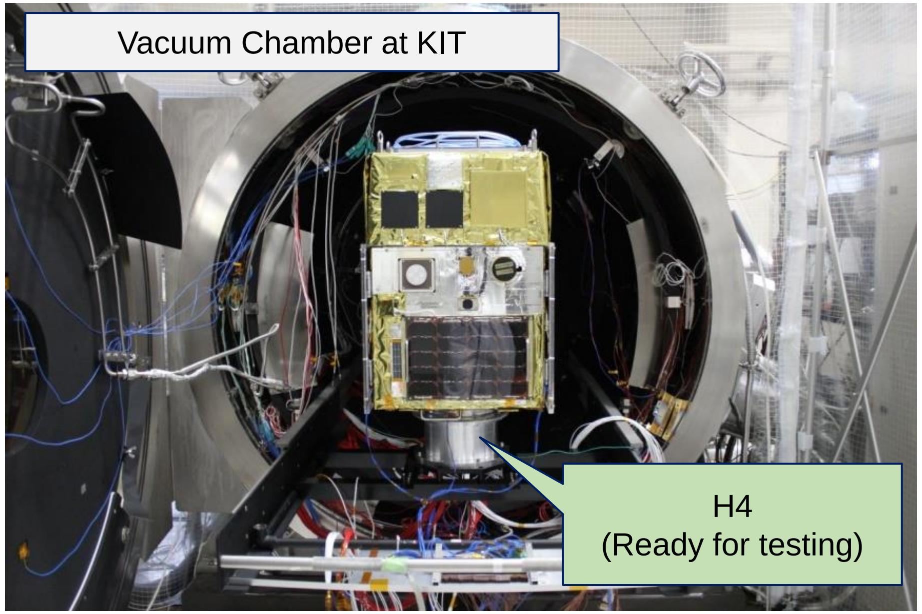


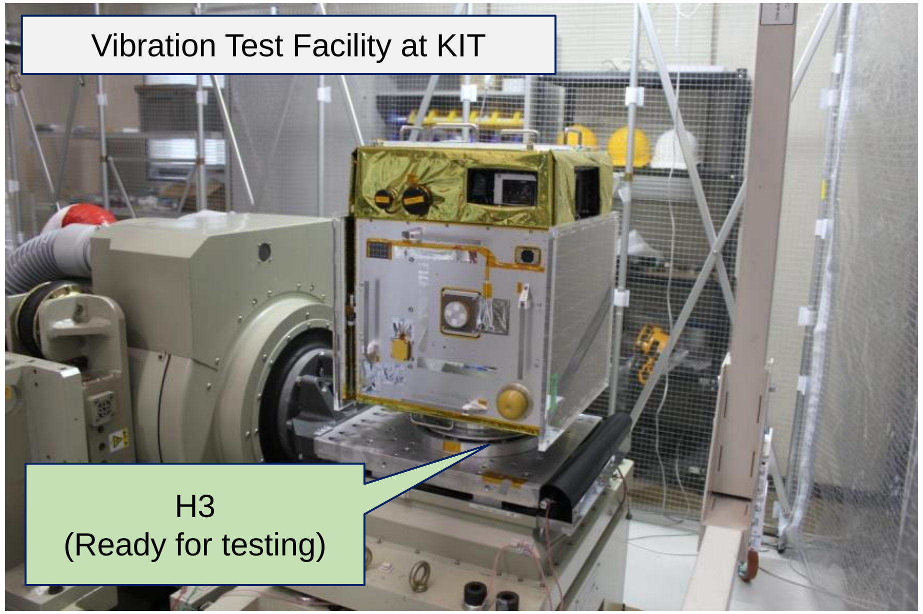
“Table-sat Test” checks proper functionalities and connections between components

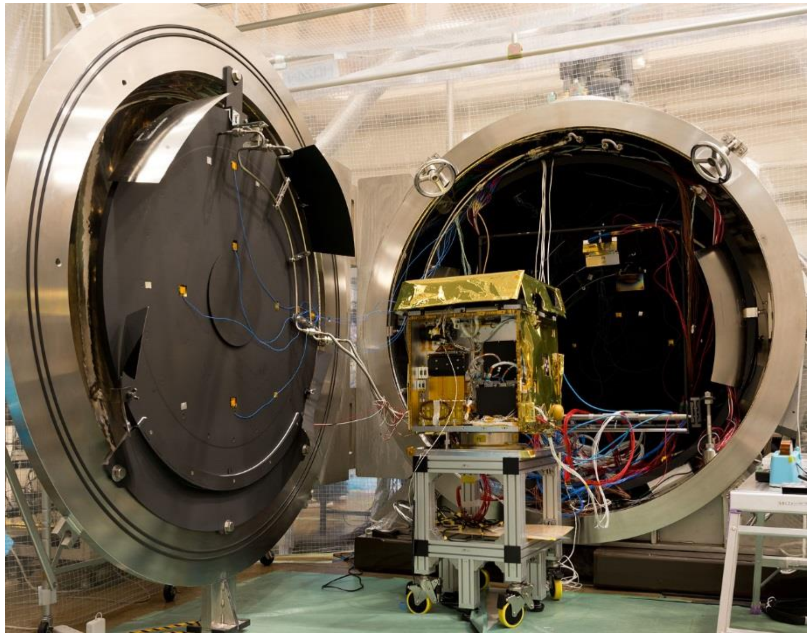
Satellite Integration



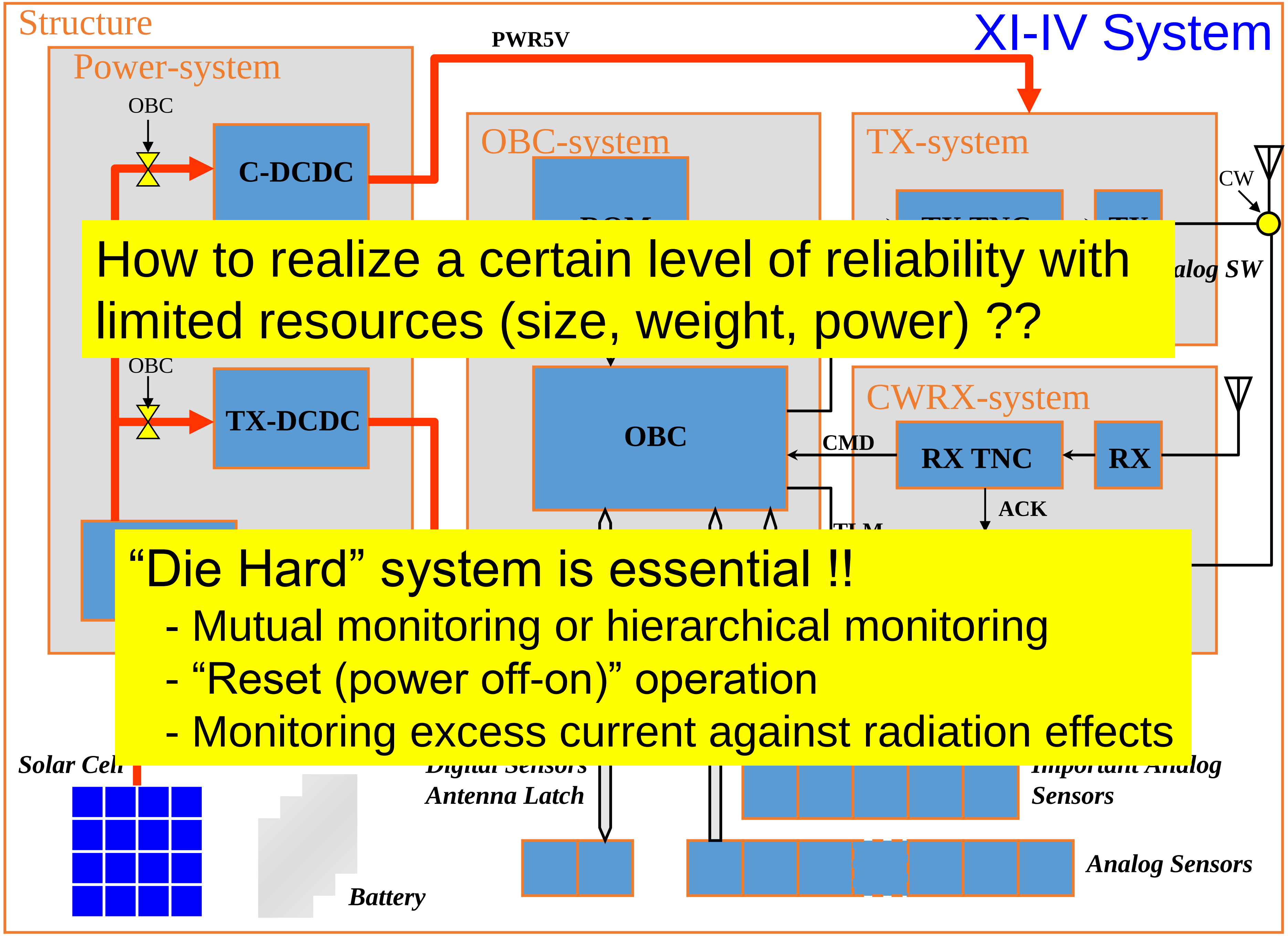
Space Environment Tests







XI-IV System

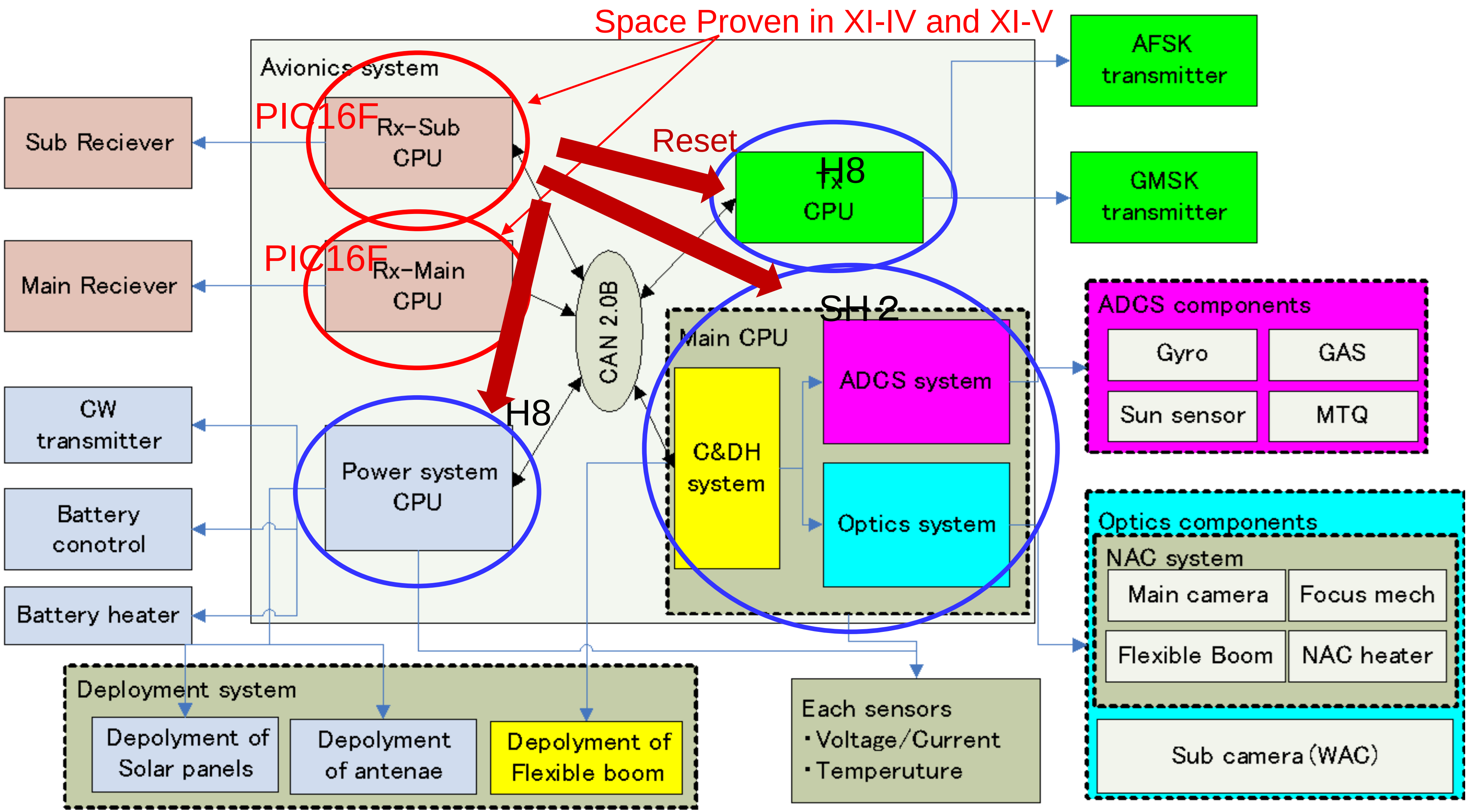


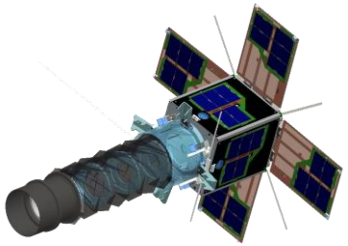
How to realize a certain level of reliability with limited resources (size, weight, power) ??

"Die Hard" system is essential !!

- Mutual monitoring or hierarchical monitoring
- "Reset (power off-on)" operation
- Monitoring excess current against radiation effects

PRISM System Diagram



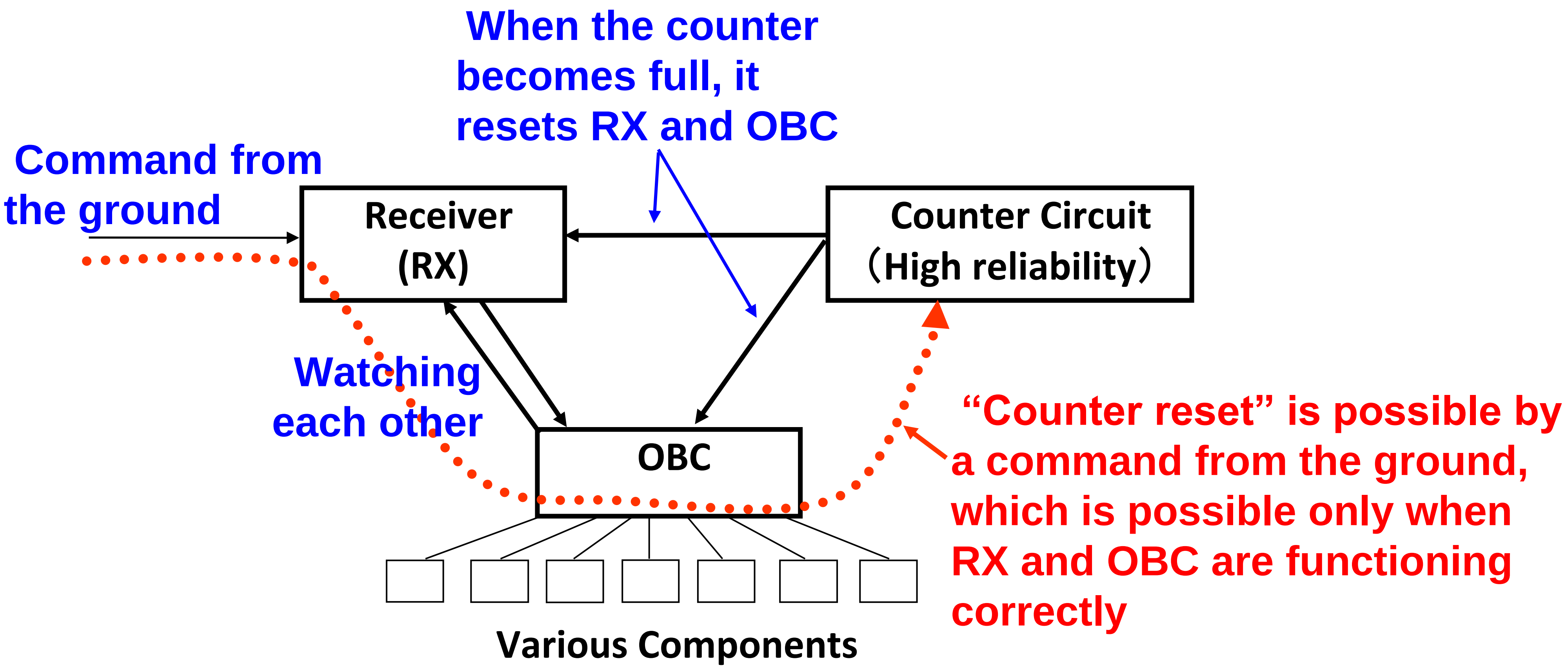


Combination of “High performance but not space-proven” processor and “Low performance but space-proven” processor

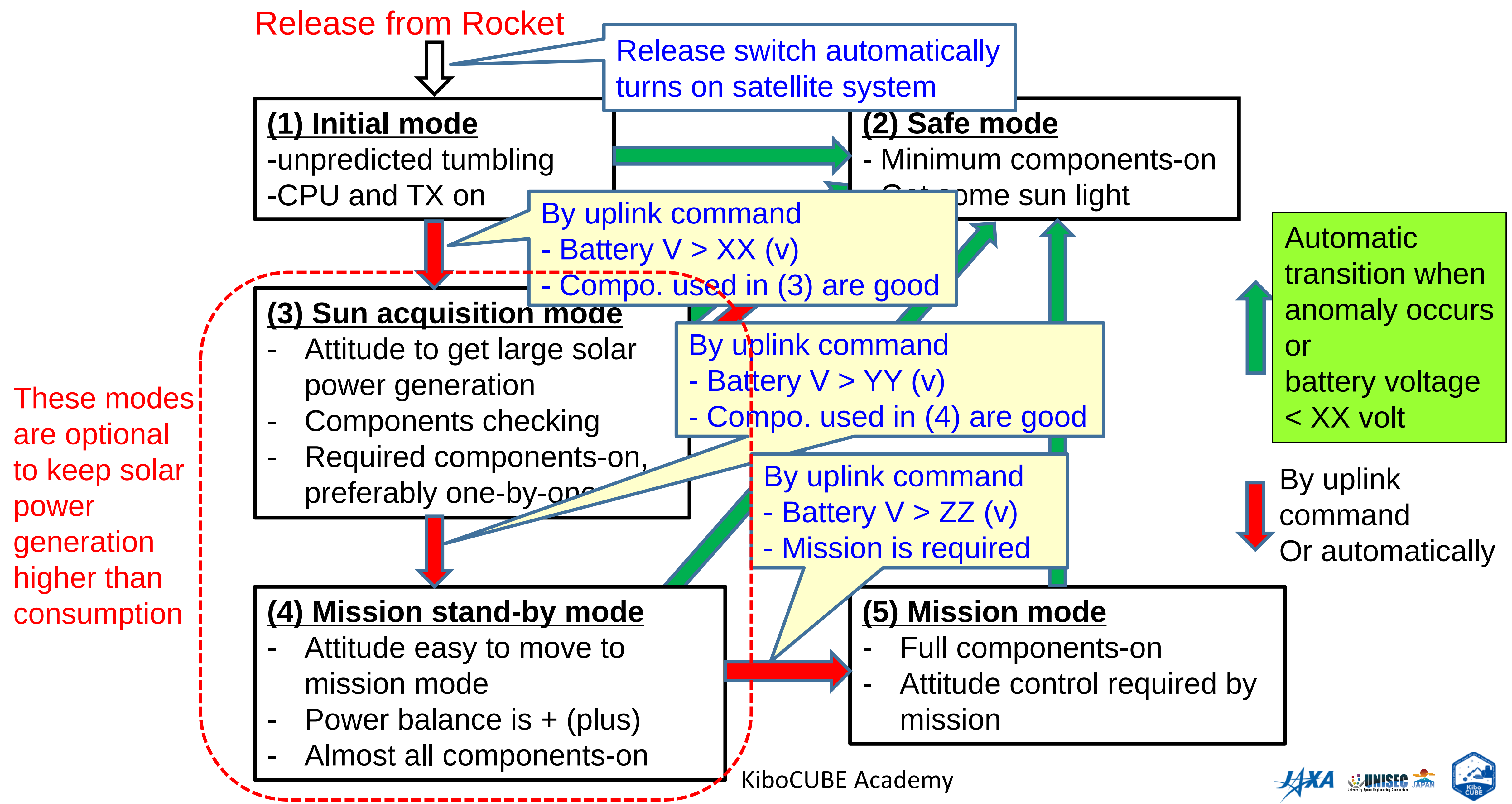
Example of Useful "Reset" Mechanism

Usage of Counter Circuit

One thoughtful idea to use a "counter circuit" for a reset mechanism



Fundamental Modes and Sequence (One Typical Example)



Transfer to Safe Mode

Prepare safe mode to enhance survivability

- Sometimes anomalous situation affect satellites such that:
  - the battery voltage drops very low
  - the downlinked telemetry include such data that cannot be explained
  - the satellite attitude motion is strange, etc.
- The maximum survivability can be obtained by making your satellite transfer to “safe mode” which assures:
  - minimum power consumption of components
  - power generation is larger than power consumption
  - sufficient data for analysis of the cause of anomaly is downlinked
- Safe mode should be designed such that it can be entered even when the ground station cannot communicate with your satellite.

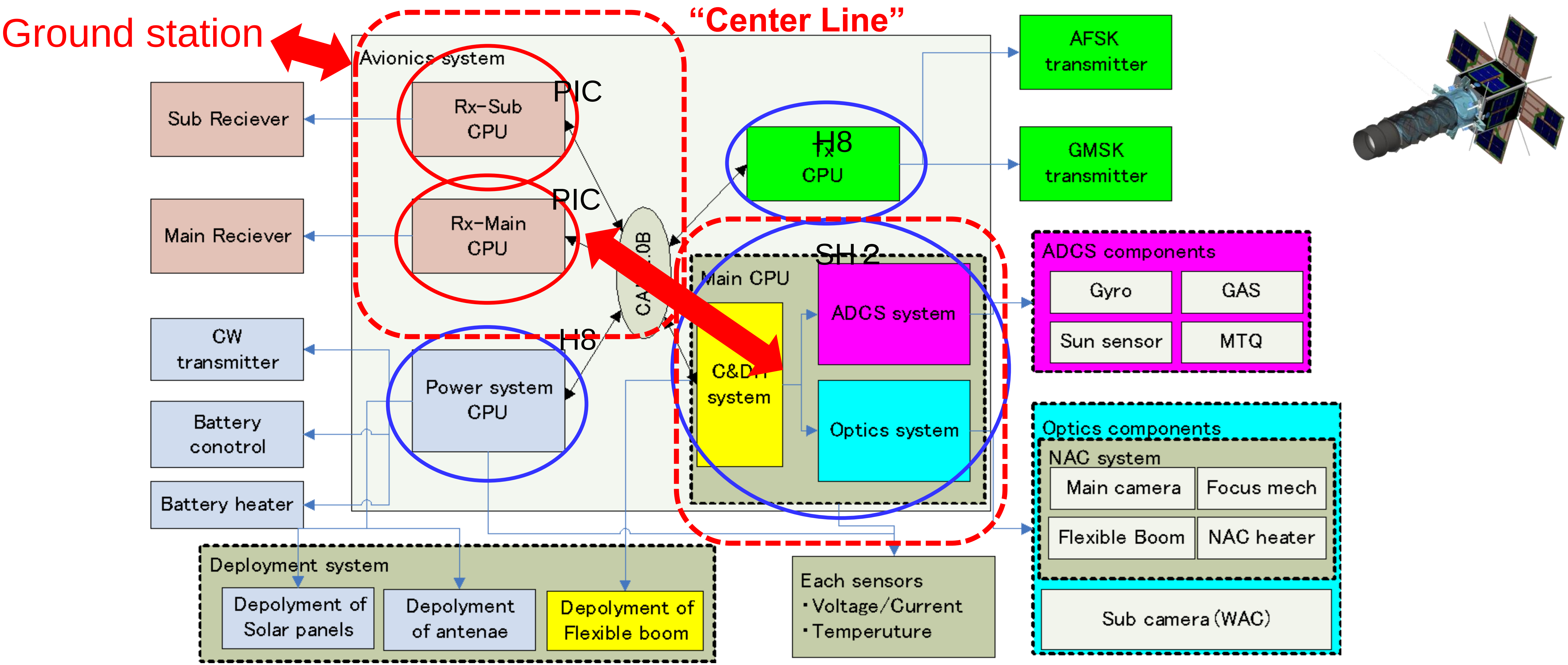
Safe mode is “Survival Mode”

Use Reliable Communication System

You should somehow communicate with the satellite.

- "Center line" is very important!
  - Assure proper functioning of the Ground station ⇒ Receiver ⇒ OBC route
  - Should use reliable CPU inside the communication receiver
  - It is recommended that command from the ground can reset components without using the OBC
- Design an effective antennae
  - Antenna should be stowed during launch, and take a proper shape after deployment
- Even if any components fail, some information should be downlinked to ground
  - For example, CW beacon can be used as a backup for telemetry downlink
- Functional redundancy
  - If you use S-band for house keeping and X-band for mission data, in case of S-band failure, X-band can also be used for downlink of house keeping telemetry

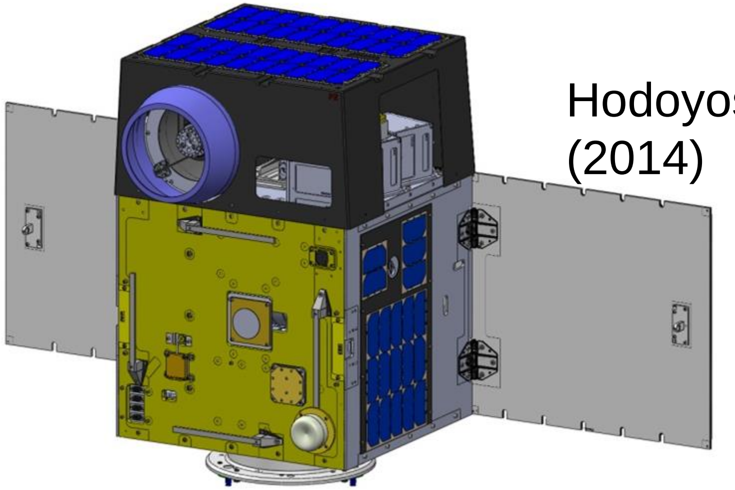
PRISM System Diagram



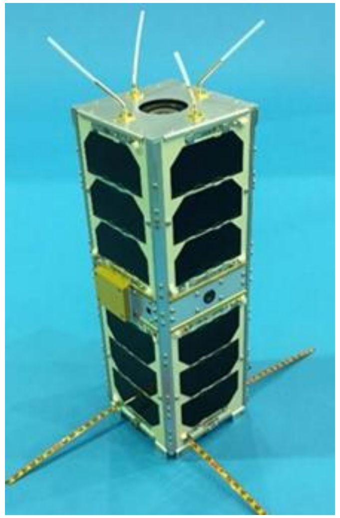
Combination of "High performance but not space-proven" processor and "Low performance but space-proven" processor

Enabling Solar Power Generation in Any Attitude

Solar paddle type vs. Body mount type



Hodoyoshi-4
(2014)

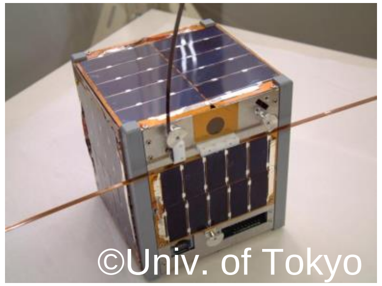


TRICOM-1R
(2018)

- ● Very large power generation
- ✓ Power generation is possible only when attitude control works properly

- ✓ Limited power generation
- ● Power generation is possible regardless of attitude

For a 1U CubeSat, body mounted cells on all the 6 surfaces are recommended.



5. Start with a very simple satellite

“Simple” is Best

- In your 1st project, start with a simple and easy-to-realize type of mission, and if you still have additional time/budget, then try to consider additional missions
  - start from “KISS” = Keep It “Stupidly Simple”
- “Functioning CubeSat in space” in itself is an important mission.
  - Pursue survivability as much as possible
- Find out and pursue what you can do with your limited resources, not aiming at too high a level (“high level” should be pursued after your first success !)
- Try to find external supporters
  - Technical consultation, testing facility, donation, etc.
  - Promotion of your activities to the general public is important

6. Study and training before building a CubeSat

Study and Training before CubeSat

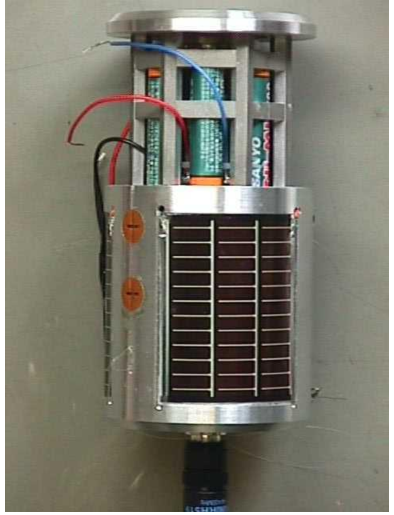
What should you learn before developing a CubeSat?

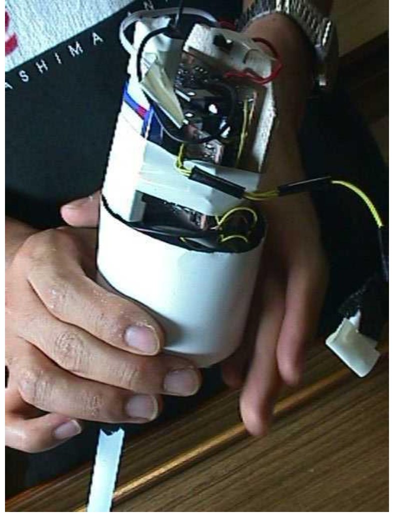
- Basic knowledge on mathematics, physics, rigid body dynamics, electronics, radio frequency…..
- Printed circuit board (PCB) design to realize certain functions
- Orbital mechanics, attitude dynamics/control and thermal/structure dynamics for space systems
- <u>Practical training using “real” projects</u>

“CanSat” is an excellent tool

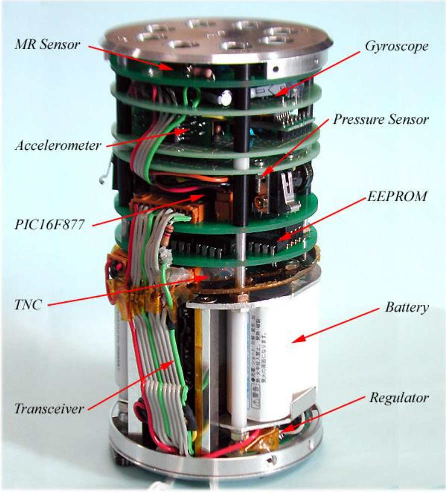
- Project management and teamwork
- System level design (weight/power budgeting, etc.)
- How to make a “die hard” system
- Ground tests and operations from the ground

Once you pass you CanSat to rocket engineers, you cannot contact it any more!





Initial Training for satellite development CanSats 1999 - now



Hands-on Training Tool: CanSat

Many universities in Japan have been trained by CanSat.

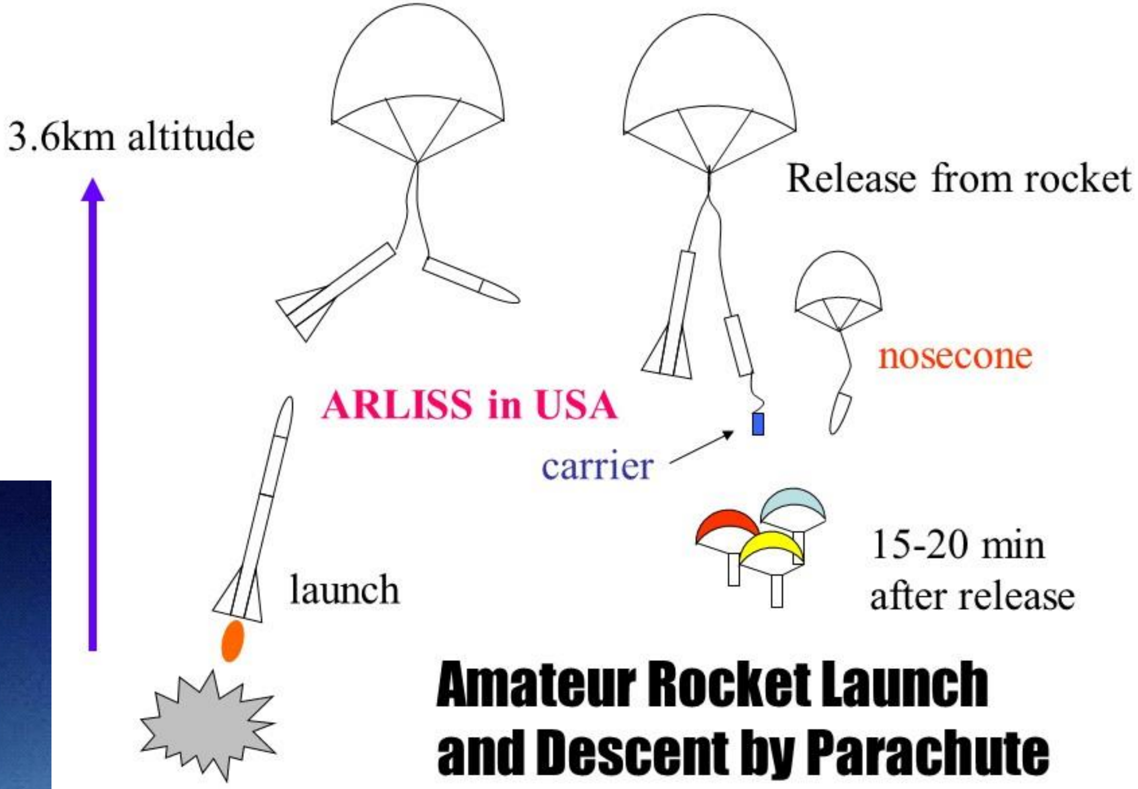
ARLISS: A Rocket Launch for International Student Satellites in Nevada, USA

AEROPAC (Amateur Rocket Group) lifts CanSat to 3.6km altitude in Nevada, and during descent (about 15 minutes), various experiments are conducted

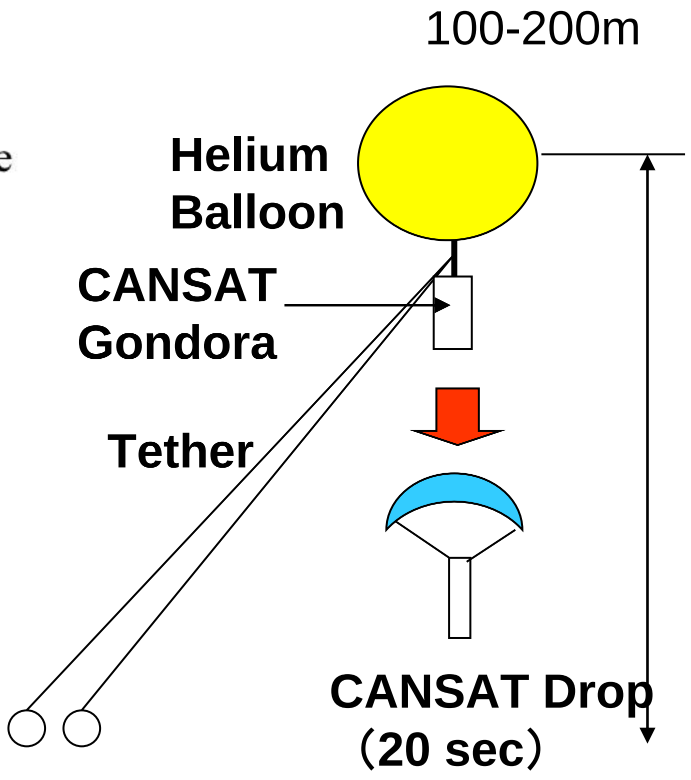
How to lift a CanSat ?

Drone or UAV have also been used recently

Simplest way: drop from a high building



Amateur Rocket Launch and Descent by Parachute



Example Mission “Comeback Competition”

CanSat International Competition in ARLISS

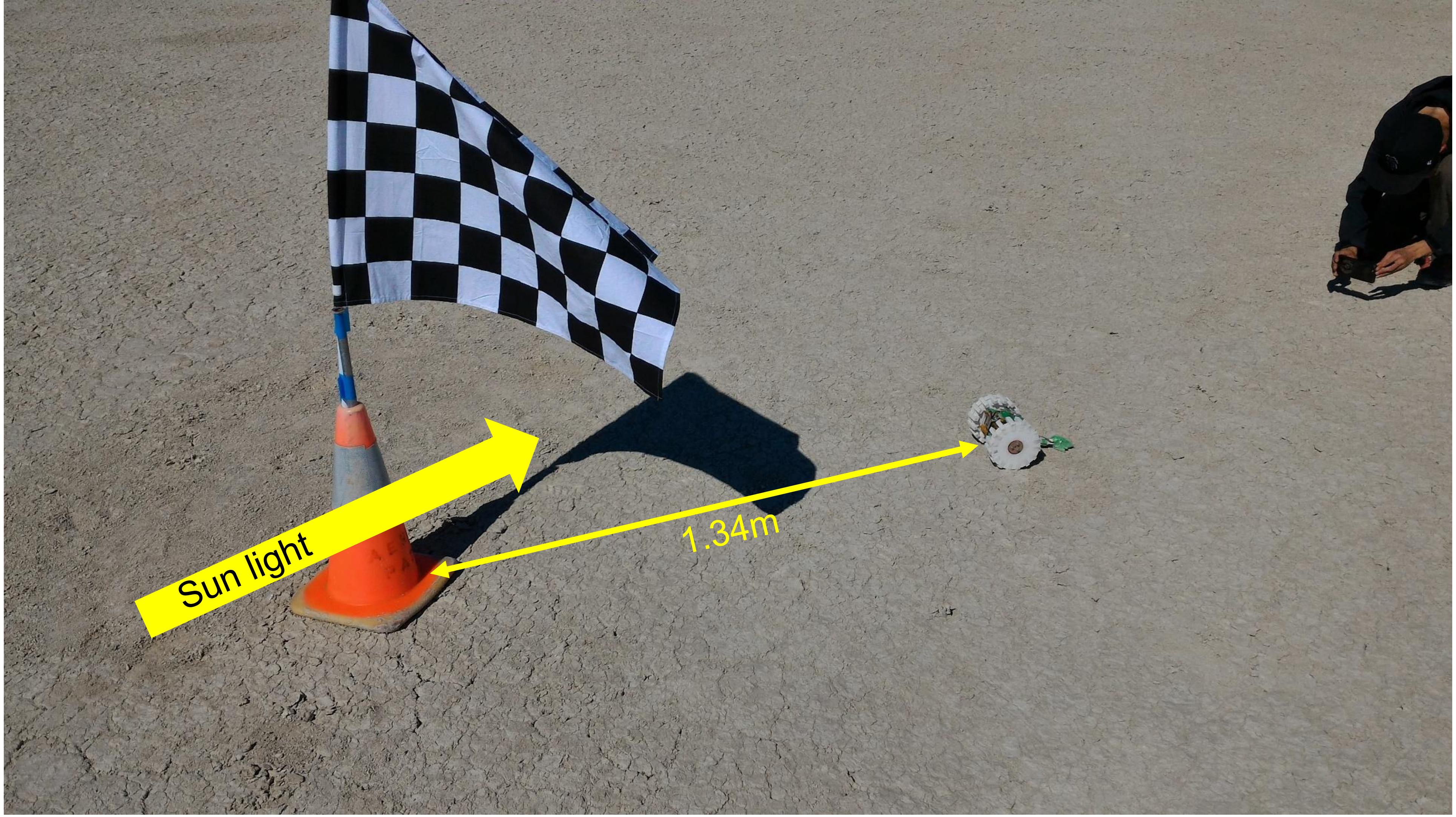
- Mission: to autonomously come back to the target after release from a rocket
  - Flyback-type (parafoil, fixed wing, drone) vs rover-type

“Problem Solving” training is important!

- Life is full of “problem solving”
  - For most of the problems, there are not answers yet.
  - Most of them cannot be solved by knowledge and skills in a single area
  - Setting “goal” by yourself is also important

- Satellite/CanSat development provides excellent opportunity of training for “problem solving”
  - No correct answers exist before
  - Cannot be developed only by single technological area
  - You can set your own goals for your project

- You can get good training **only when you have strong desire to solve the problem !!**
  - Satellite/CanSat development provides this motivation



2017, our team reached 1.34m to the target by GPS navigation, and changed to “camera navigation” to reach the target. But…

Because of coming sun-light, its camera could not recognize the target and gave up after some waiting time.

They still had one more chance on two days after…

- They modified the strategy and changed the software.
- They did on-site tests many times to check the new software.
- And realize “0 m” to the target in their second run !!

This is really a “problem solving” !!

Strong motivation “We want to win the competition!”

Failure is also an Education

Parachute and main body were separated and the main body crashed on the ground (2000)

- Students can learn many things from failures
- Engineers should experience failures while the project size is small

CLTP (CanSat education) History & Participants

CLTP1 (Wakayama Univ. in Feb-March, 2011)
12 participants from 10 countries, Algeria, Australia, Egypt, Guatemala, Mexico, Nigeria, Peru, Sri Lanka, Turkey (3), Vietnam.

CLTP2 (Nihon Univ. in Nov-Dec, 2011)
10 participants from 10 countries, Indonesia, Malaysia, Nigeria, Vietnam, Ghana, Peru, Singapore, Mongolia, Thailand, Turkey.

CLTP3 (Tokyo Metropolitan Univ. in July-August, 2012)
10 participants from 9 countries, Egypt (2), Nigeria, Namibia, Turkey, Lithuania, Mongolia, Israel, Philippines, Brazil.

96 participants from 46 countries

<2013~ iCanSat Kit: CLTP4-7>

CLTP4 (Keio Univ. in July-August, 2013)
9 participants from 6 countries, Mexico(4), Angola, Mongolia, The Philippines, Bangladesh, Japan.

CLTP5 (Hokkaido Univ. in Sept, 2014)
7 participants from 5 countries, Korea (2), Peru, Mongolia, Mexico (2), Egypt.

CLTP6(Hokkaido Univ. in August, 2015)
8 participants from 8 countries, namely Angola, UN(Austria), New Zealand, Tunisia, Turkey, Egypt, Bangladesh, Mexico

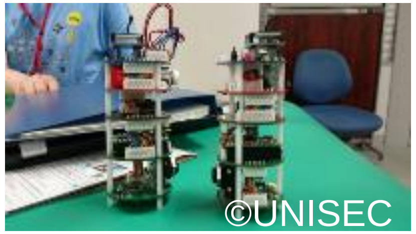
CLTP7 (Hokkaido Univ. in Sep, 2016)
8 from 7 countries, namely Egypt, Myanmar, Peru, Nepal (2), Mongolia, Serbia, Dominican Republic

<2017~ HEPTA-Sat Kit: CLTP8-10>

CLTP8 (Nihon Univ. in Sep, 2017)
9 from 7 countries, namely Bolivia, Egypt, El Salvador, Malaysia, Nepal, Turkey

CLTP9 (Nihon Univ. in Aug, 2018)
8 from 6 countries, namely Argentina, India, Japan, Malaysia, Mongolia, UAE

CLTP10 (Nihon Univ. in Aug, 2019)
15 from 11 countries, namely Australia, Bhutan, Bulgaria, Cambodia, Colombia, Kenya, Morocco, Myanmar, Peru, Rwanda, Zimbabwe



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7. Define the Target Outcome of the Project

Various Options for Satellite Development

You can buy CubeSat components from websites easily. How to mix purchased components and ones of your own design?

1) **Assemble purchased components with a fixed mission (i.e.,"kit") , do ground tests, and launch/operation**

Option 1-1) Add one original mission with your own designed component

2) **Create your own mission, buy components to realize it, do ground tests, and launch/operation**

Option 2-1) Design/fabricate a few components

Option 2-2) Design/fabricate all the components ⬅What we did for our first CubeSat

Find an adequate option considering your team's expertise and your target outcomes.

Expertise to be Obtained by Project

What can you learn in each option ?

Options	Mission creation	Architec-ture design	System Analysis	Sub system design	Project manage-ment	AI&T	Ground operation
1)					s	s	L
1-1)	s	s	s	s	s	L	L
2)	L	L	L		L	L	L
2-1)	L	L	L	s	L	L	L
2-2)	L	L	L	L	L	L	L

Purchased Kit + design/fabrication of one original mission by yourself

Original mission with purchased components + some designed components

Two recommen-ded options

easier

more difficult

Note) **AI&T** **A**ssembly, **I**ntegration and **T**est "s":small effect "L":large effect

Various Skills to be Obtained

CubeSat or satellite projects will give you……

- ***Practical Training of Whole Cycle of a Space Project***
  - Mission conceptualization, satellite design, fabrication, ground test, modification, launch and operation
  - Know what is important and what is not.
- ***Important Experience of Engineering***
  - "Synthesis" (not analysis) to realize your mission
  - Feedback from the real world to evaluate design, test, etc.
  - Learning from failures (while the project cost is small)
- ***Education in Project Management***
  - Four Managements: *"Time, human resource, cost and risk"*
  - Team work, conflict resolution, discussion, documentation
  - International cooperation, negotiation, mutual understanding

- ***Also contributes to other technological areas !***

8. Conclusions

Keep these in mind!

- Survivability in space is the most important.
  Imagine as many possible failures as you can and prepare countermeasures against them.
- “Reset” is an effective way to recover your satellite from anomalies. Please prepare effective ways to do a “reset”.
- Start with a very simple CubeSat. After your first success, you can step up to more sophisticated satellites.
- Study various knowledge, skills, and project management before developing a satellite. CanSat type of hands-on training is very effective!
- Define the target outcome of your project. Only the launch and operation of your first satellite is not enough. You can get something and continue it to your next project.
- Have fun! This spirit will provide you with energy, endurance, and a never-give-up mindset!

Thank you very much.

[Disclaimer]
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