KiboCUBE Academy

Lecture 04

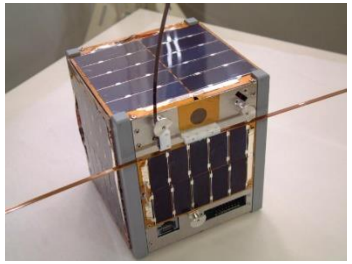
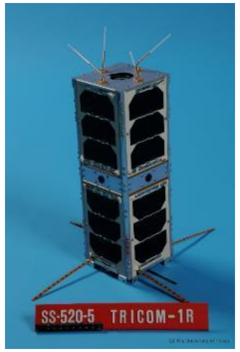
Systems Engineering for Micro/nano/pico-satellites

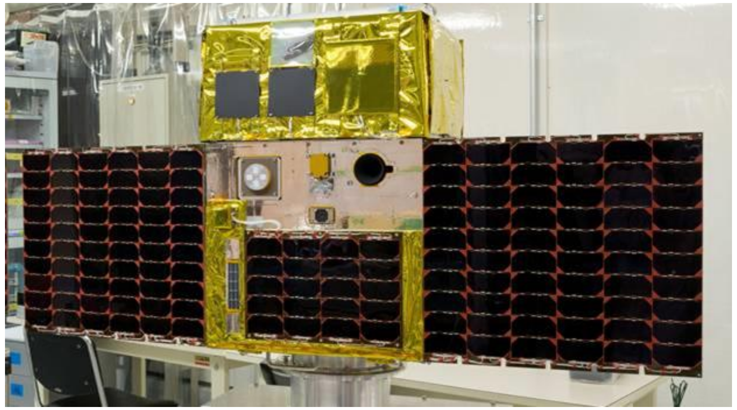
University of Tokyo

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.

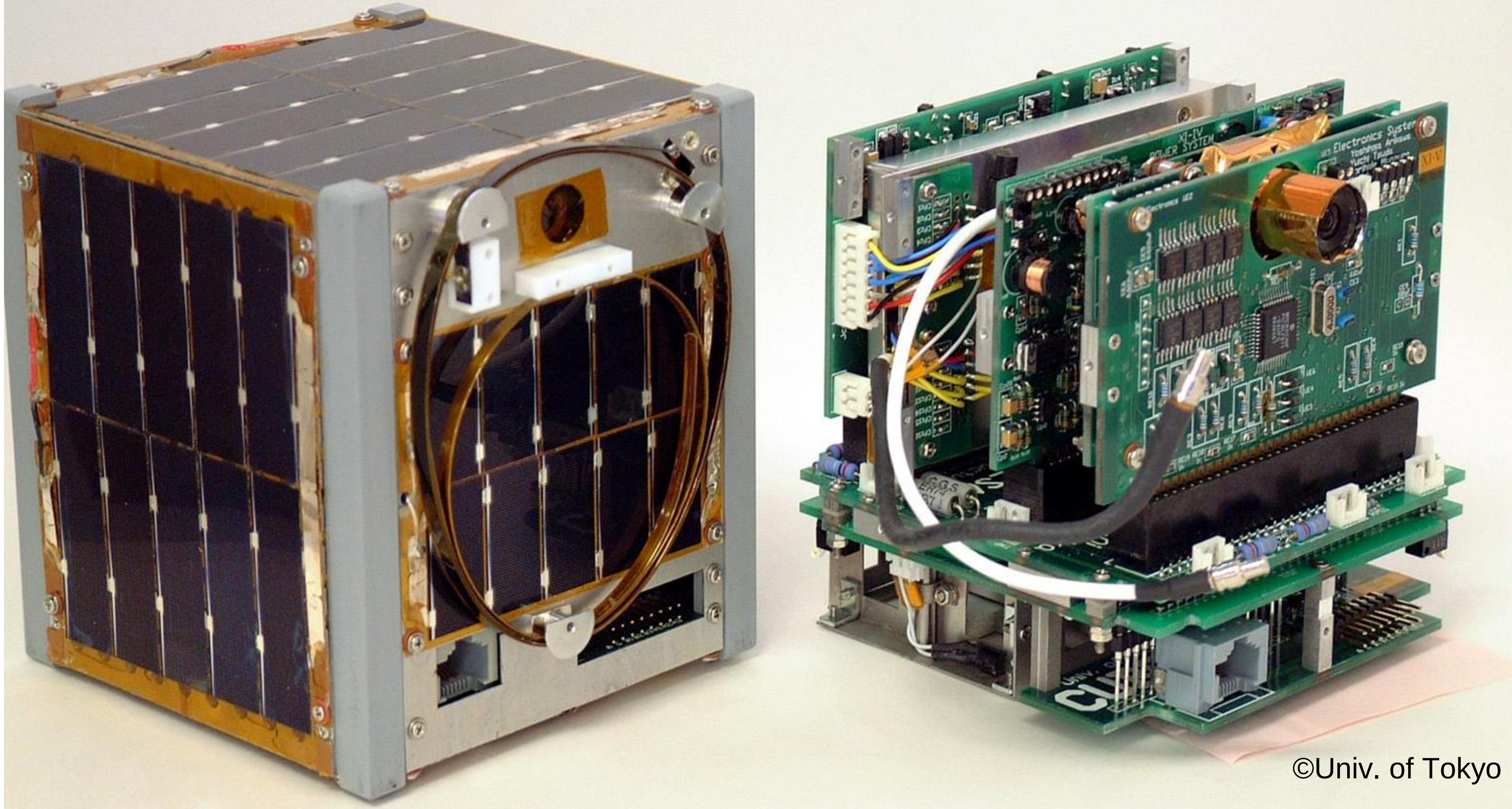
Position:

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
2013 - Chairperson, UNISEC-GLOBAL

Research Topics:

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

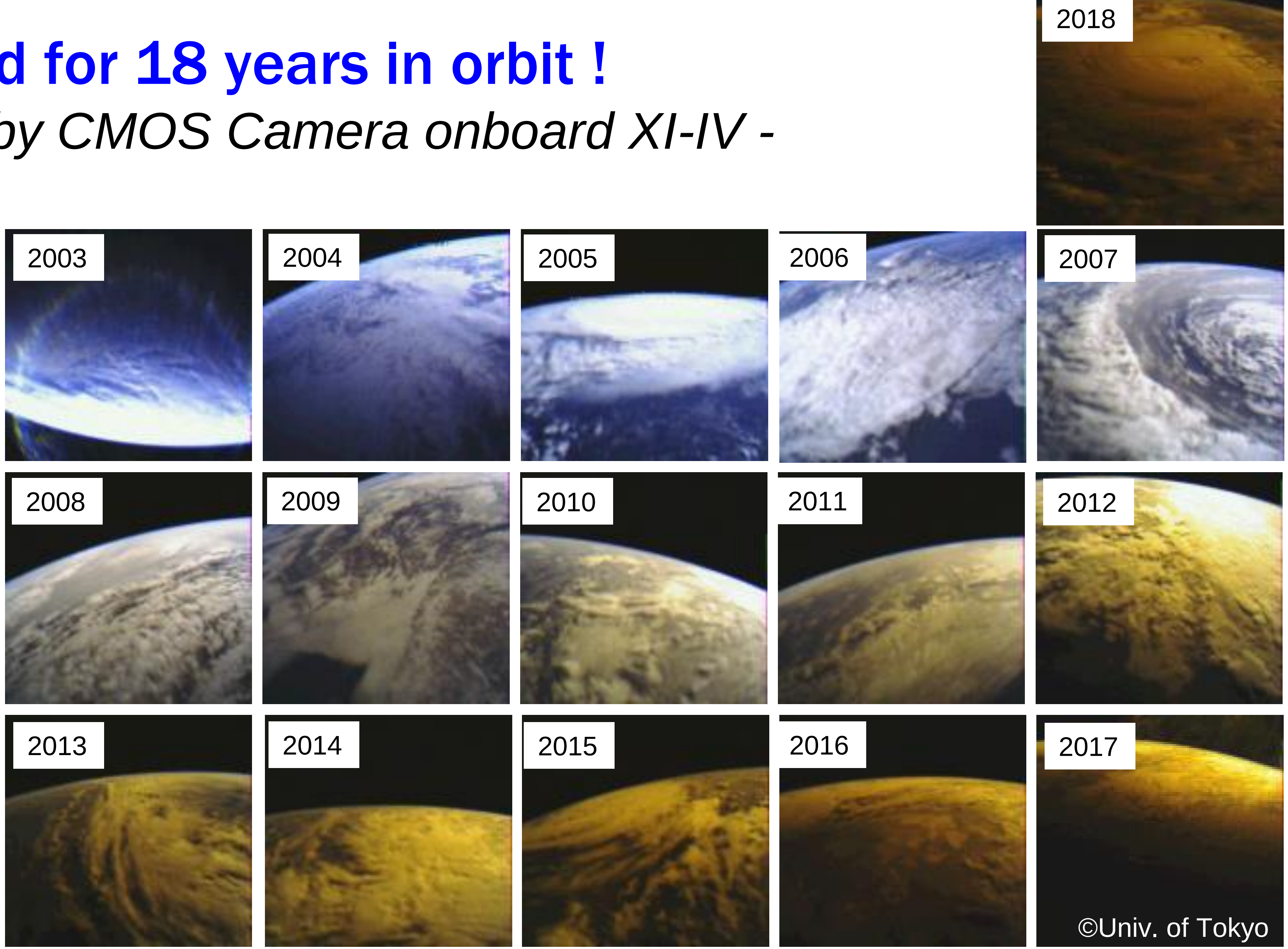
University of Tokyo's CubeSat Project "XI"



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

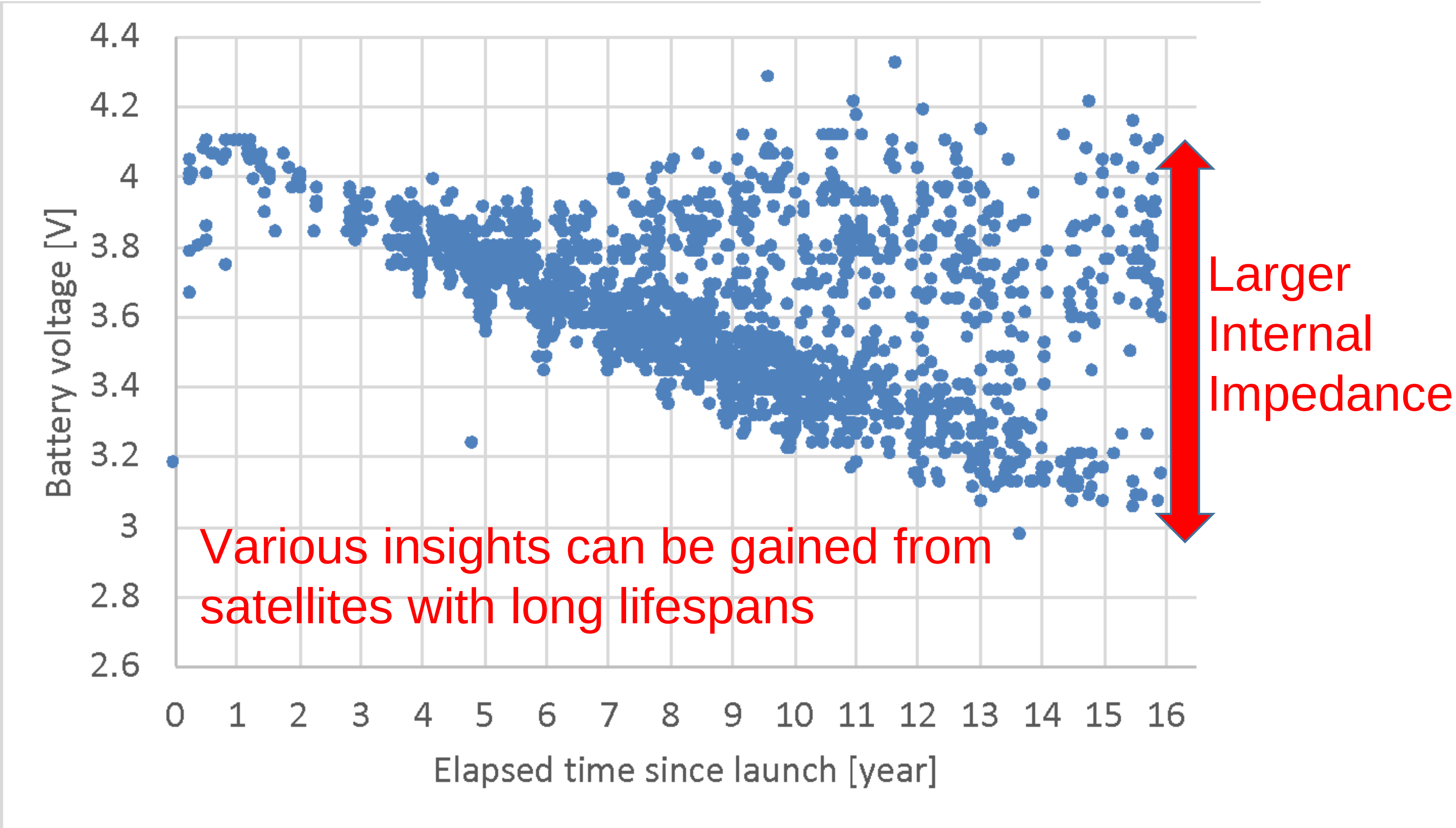
Survived for 18 years in orbit !

- Image by CMOS Camera onboard XI-IV -



18-year trend in space

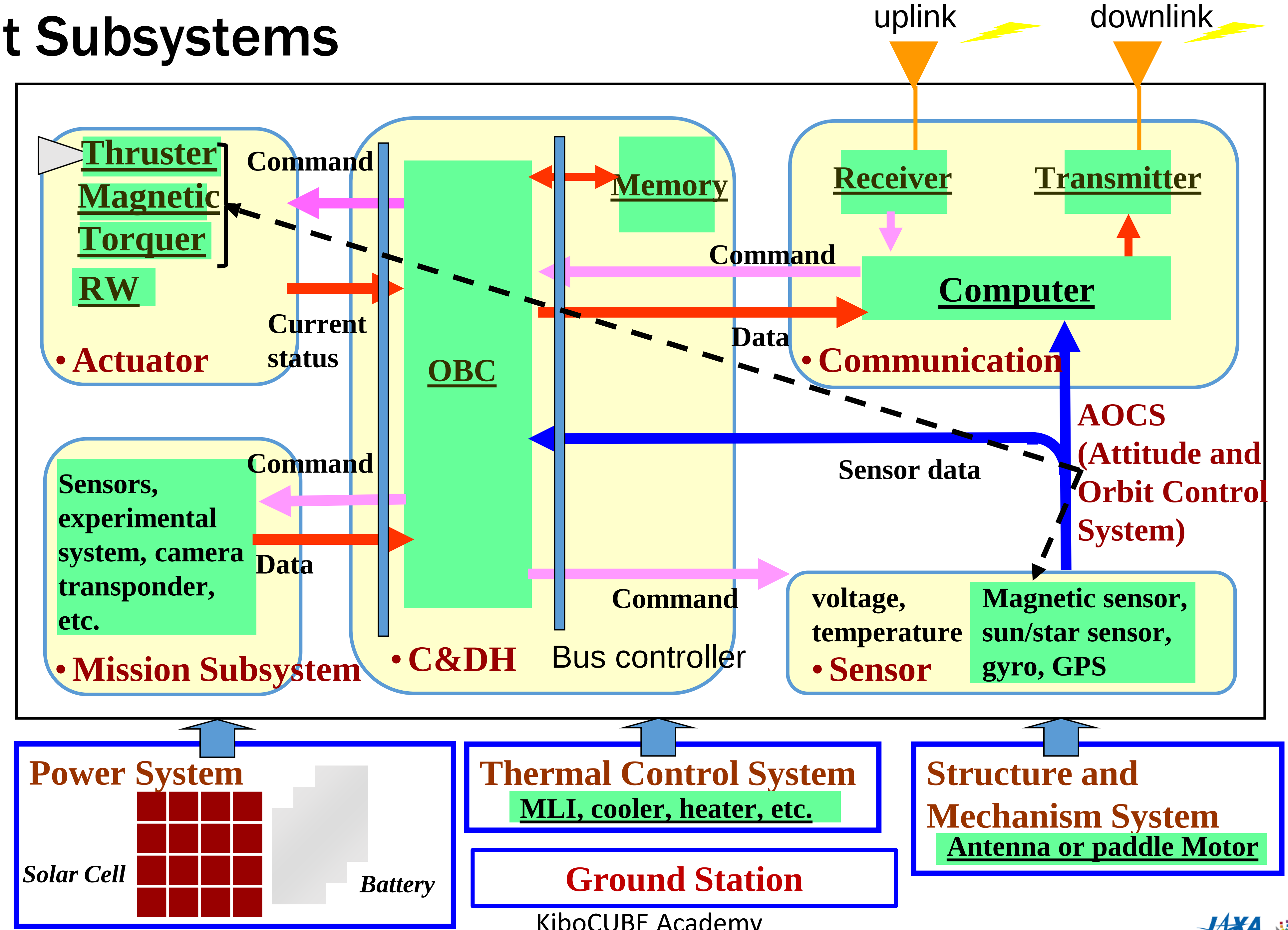
- Li-ion battery voltage history -



Contents

1. Subsystems and their relationships

CubeSat Subsystems



Relationships between Subsystems

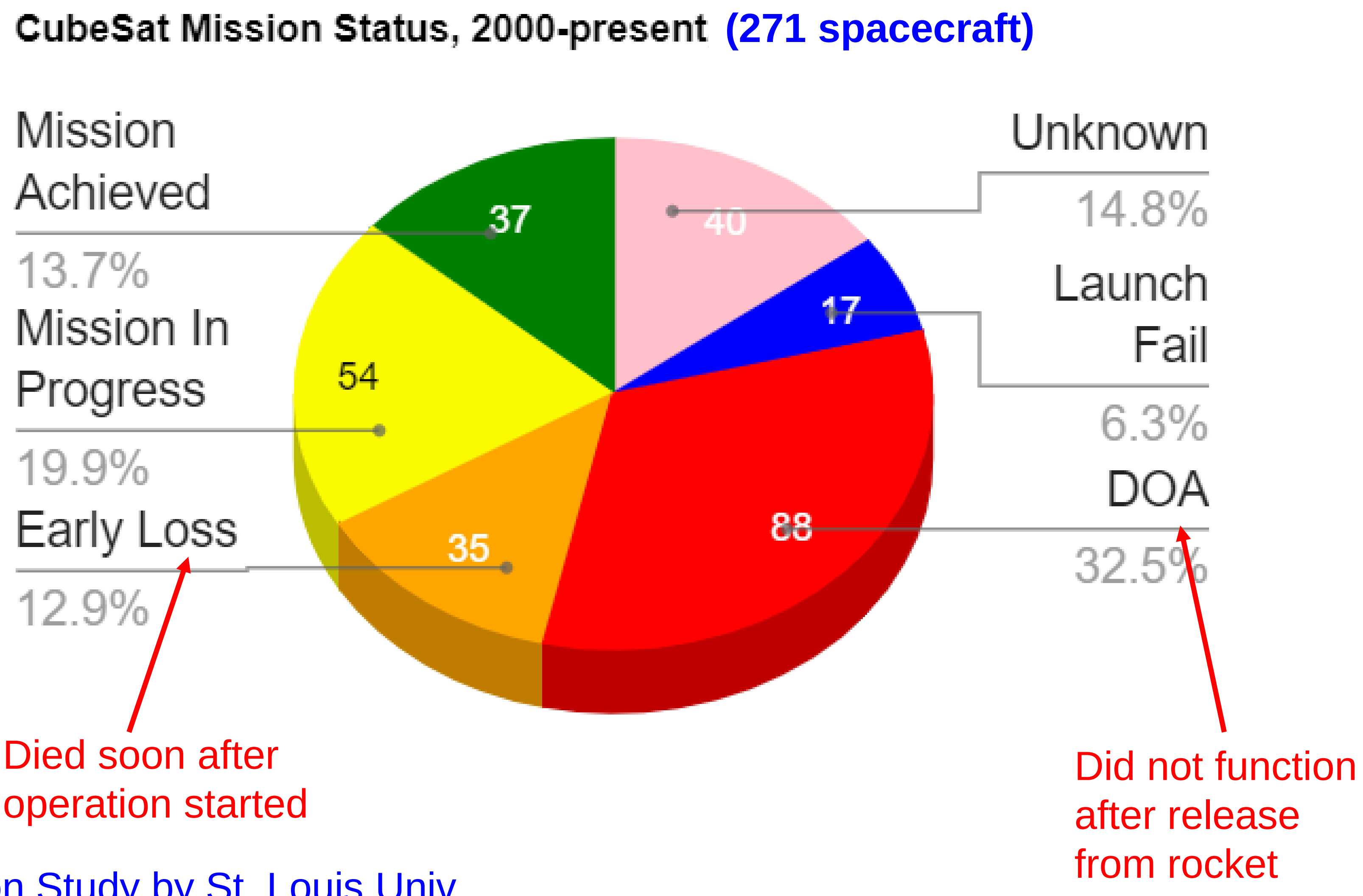
You should design subsystem interfaces properly.

- How many 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
  - What kind of data to be transferred
- 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 about 50%



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

"Water flow" project management and lots of ground tests

Review

Ground Tests

Mission Creation — System level design

↓

Breadboard Model (BBM) Phase — Trial-and-error of detailed design

- Radiation tests
- Simple function tests on TableSat

↓ PDR

Engineering Model (EM) Phase — Assuring functions in space environment

- Space environment tests (vibration, shock, thermal, thermal vacuum tests) with strong load (Qualification Test)

↓ CDR

Flight Model (FM) Phase — Fabrication as designed

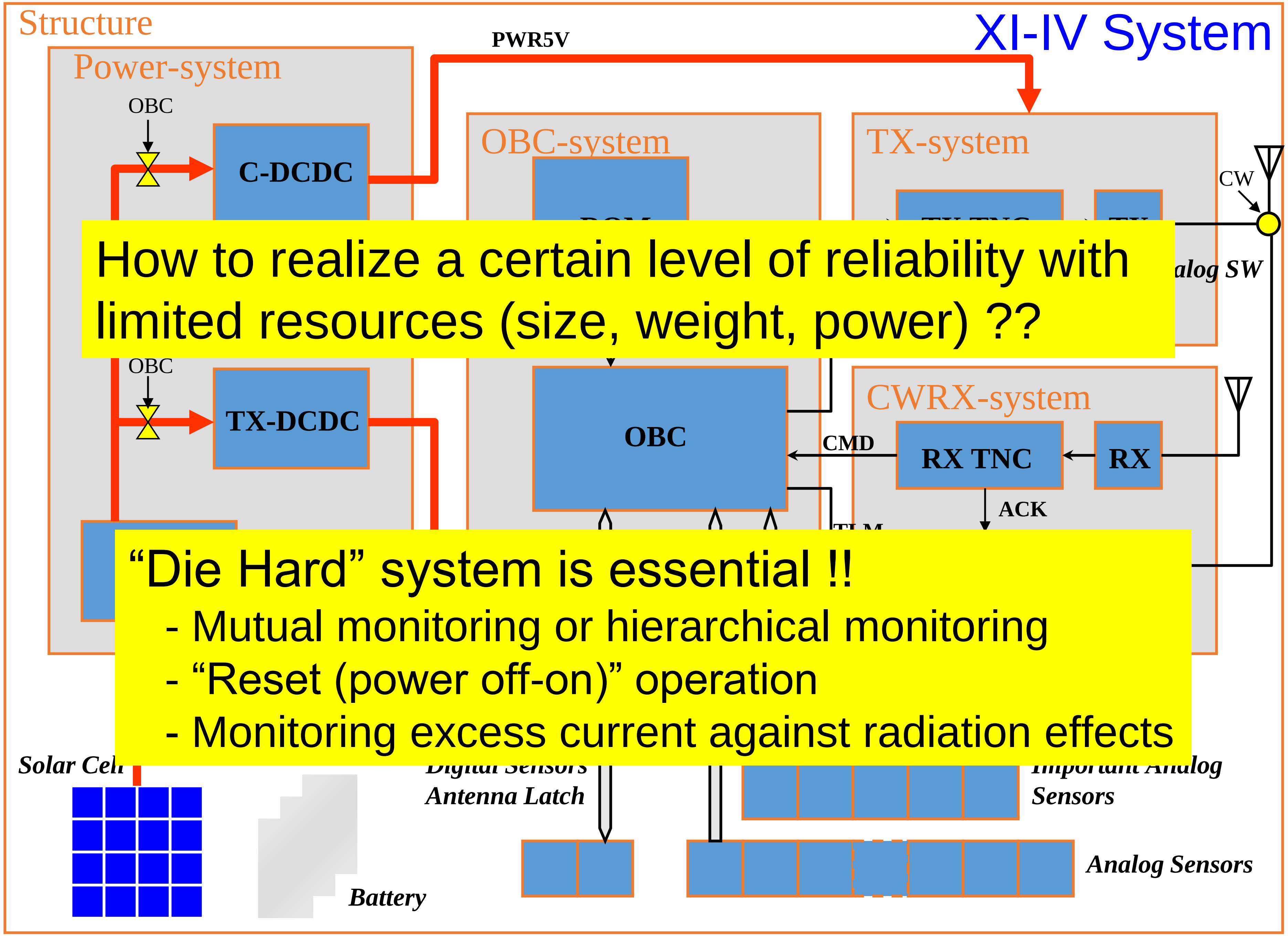
- Space environment tests (vibration, shock, thermal, thermal vacuum tests) with launch load (Acceptance Test)

↓ LRR

Launch & Operation

“Table-sat” assures proper functionalities and connections between components

XI-IV System

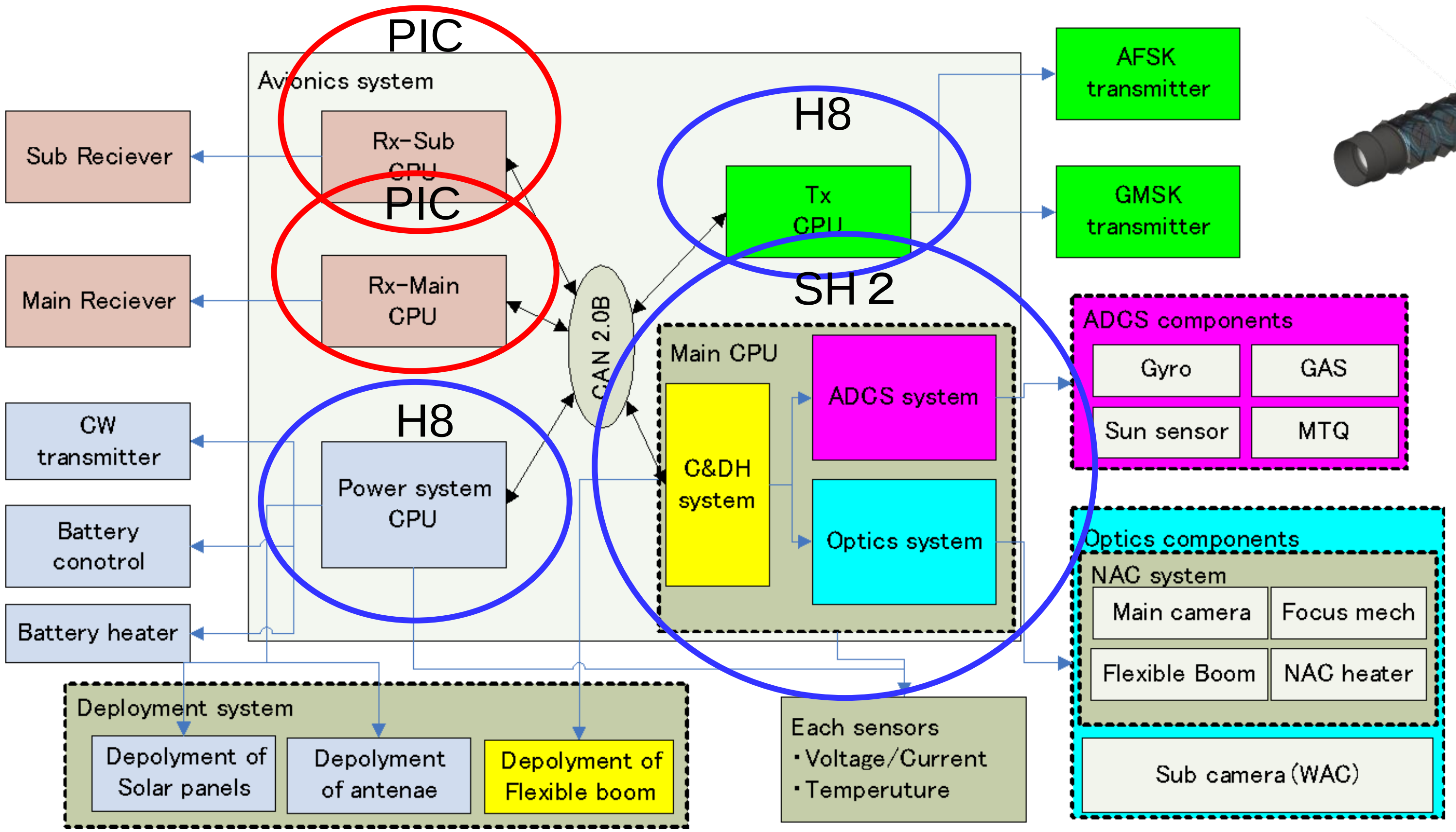


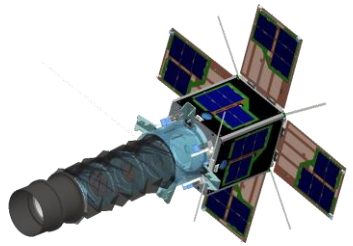
How to realize a certain level of reliability with limited resources (size, weight, power) ??

“Die Hard” system is essential !!

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

PRISM System Diagram



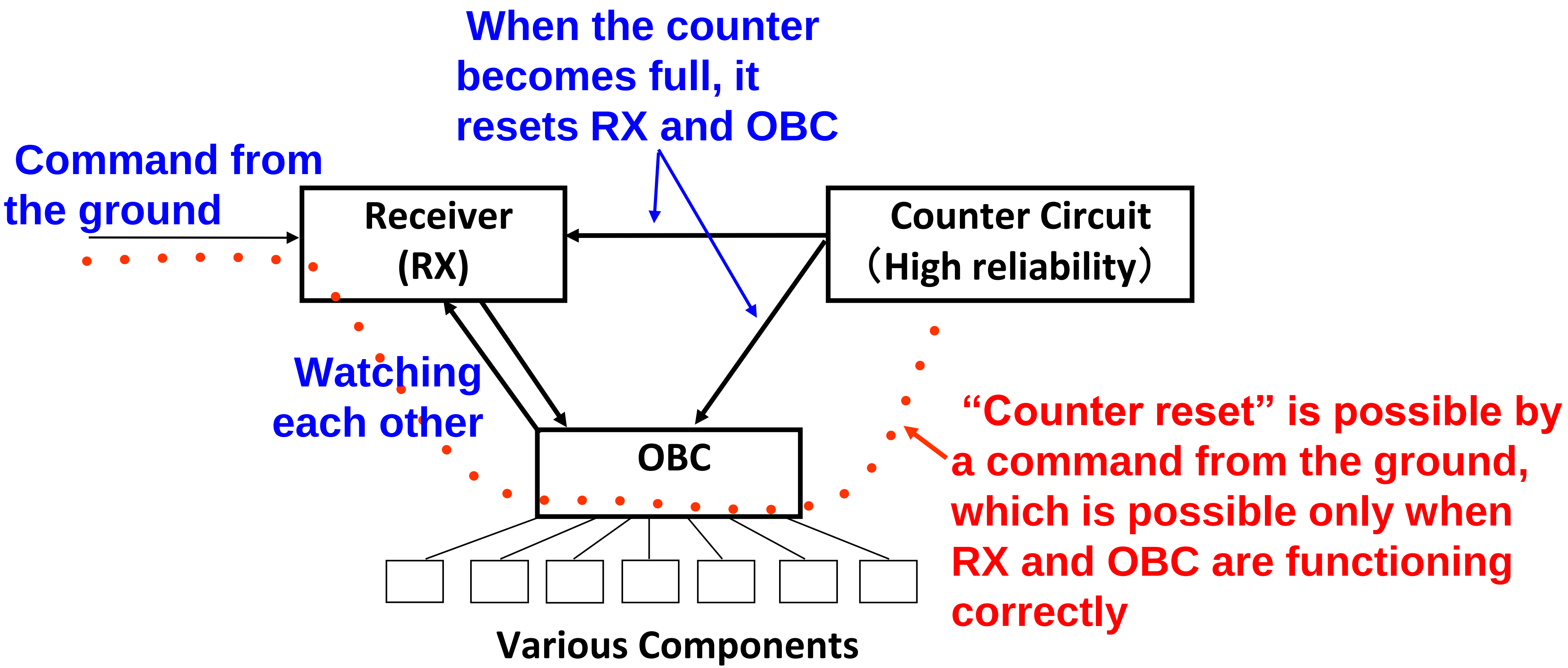


Combination of "High performance but not space-proven" processor and "Low performance but space-proven" processor

Example of Useful "Reset" Mechanism

Usage of Counter Circuit

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



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"

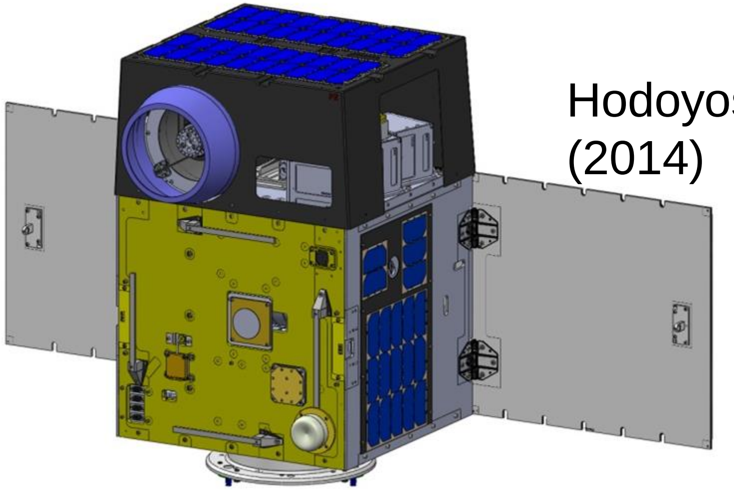
Use Reliable Communication System

You should somehow communicate with the satellite.

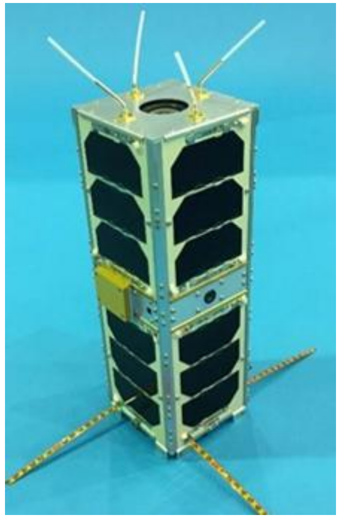
- "Center line" is very important!
  - Assure proper functioning of the Ground station ⇒ Receiver ⇒ OBC route
  - Should use reliable CPU inside the communication receiver
  - It is recommended that command from the ground can reset components without using the OBC
- Design an effective antennae
  - 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

Solar Power Generation in Any Attitude

Solar paddle type vs. Body mount type



Hodoyoshi-4 (2014)

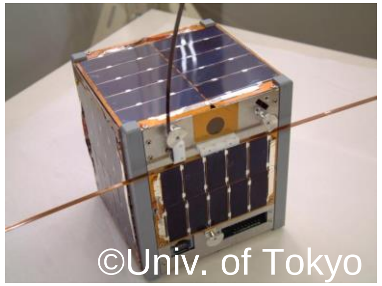


TRICOM-1R (2018)

- Very large power generation
- ✔ Power generation is possible only when attitude control works

- ✔ 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
- 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
- Practical training using “real” projects

“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

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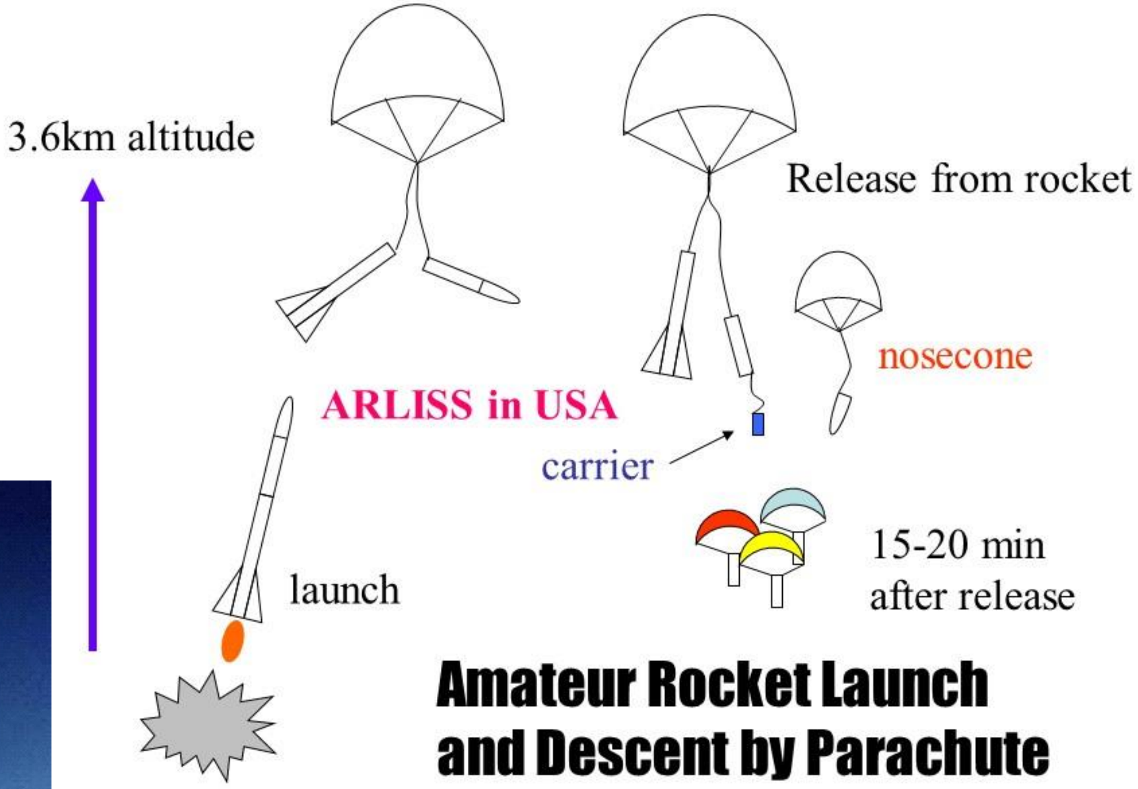
Hands-on Training Tool: CanSat

Universities in Japan have been trained by CanSat.

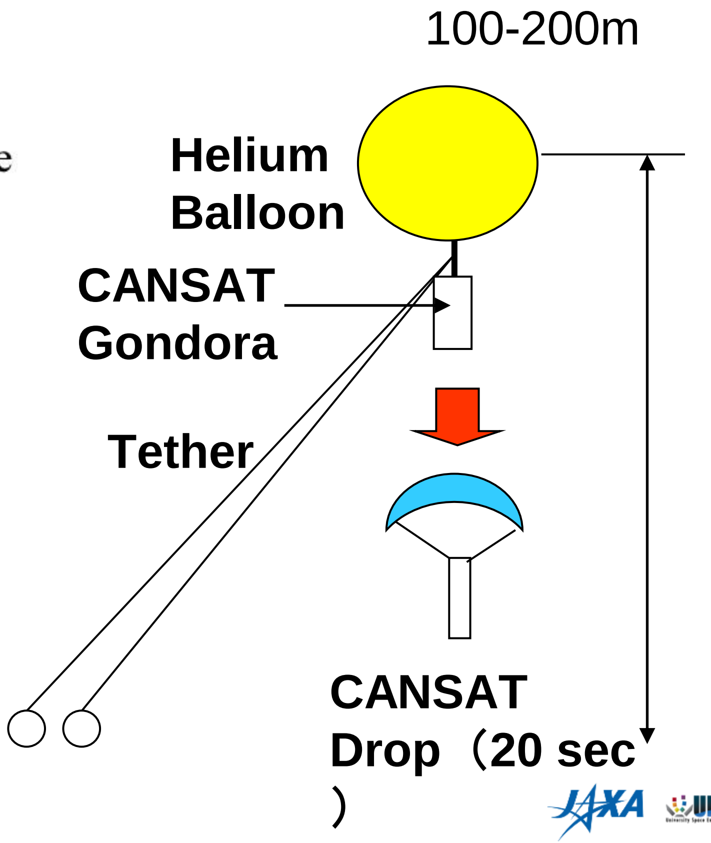
ARLISS: A Rocket Launch for International Student Satellites in Nevada, USA

How to lift a CanSat ?



Drone or UAV have also been used recently

Simplest way: drop from a high building



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

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

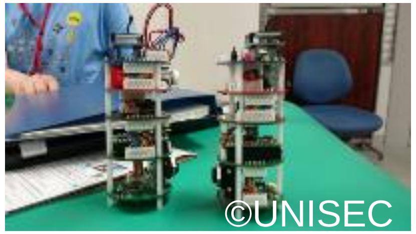
CLTP7 (Hokkaido Univ. in Sep, 2016)
8 from 7 countries, namely Egypt, Myanmar, Peru, Nepal (2), Mongolia, Serbia, Dominican Republic

<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



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

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

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.

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