KiboCUBE Academy

Lecture 03

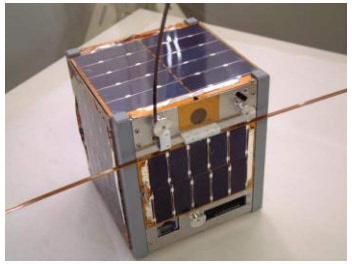
Overview of Project Management of Satellite Development

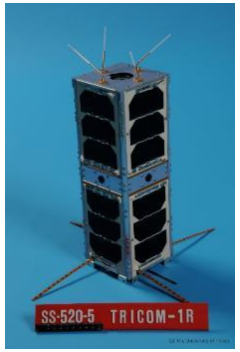
University of Tokyo

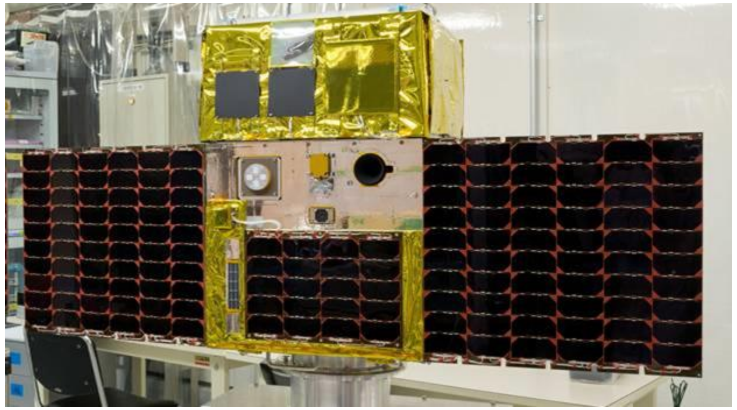
Shinichi Nakasuka

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

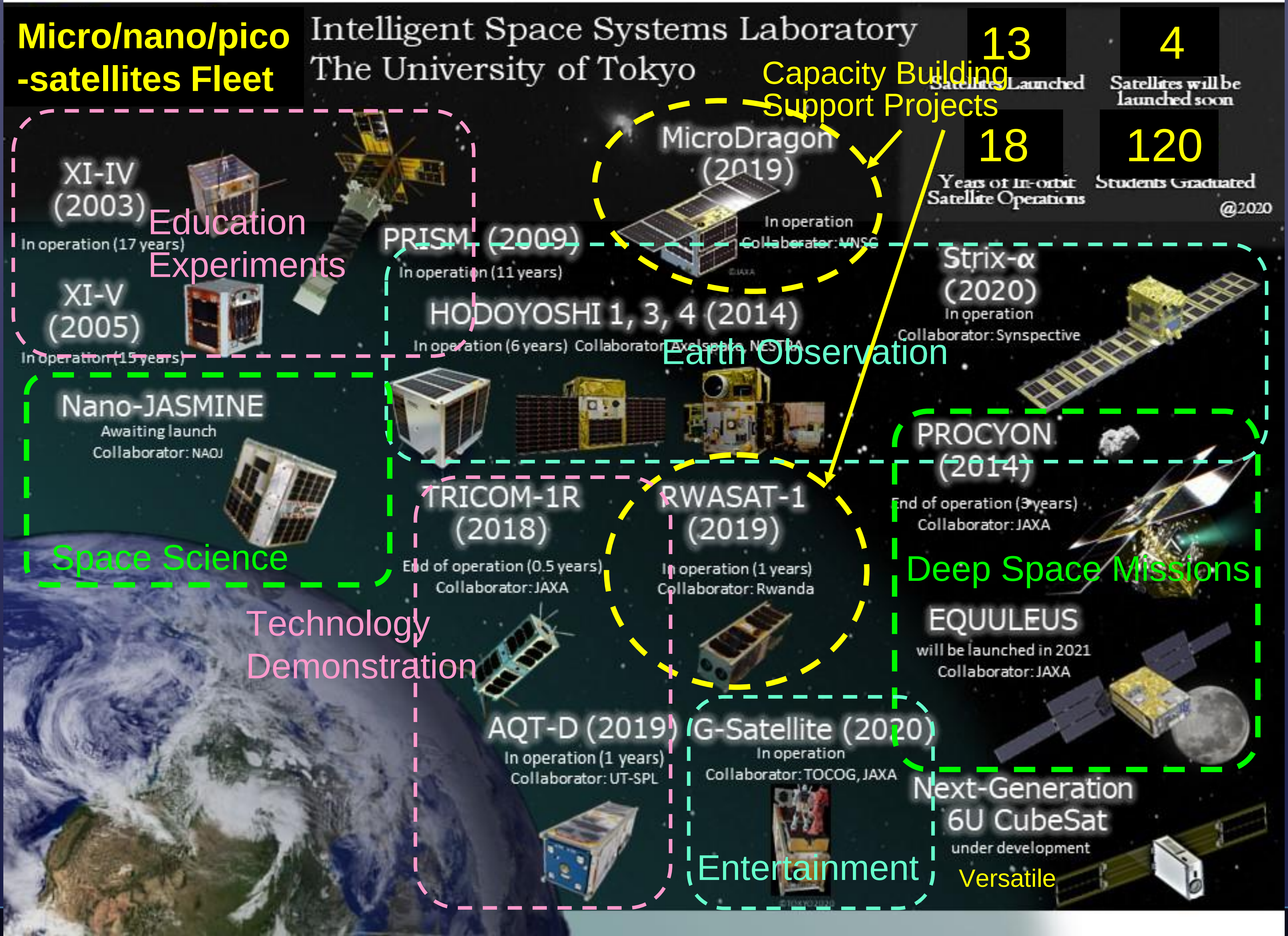
2012 - Member of Space Policy Committee, Cabinet Office

2013 - Chairperson, UNISEC-GLOBAL

Research Topics:

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

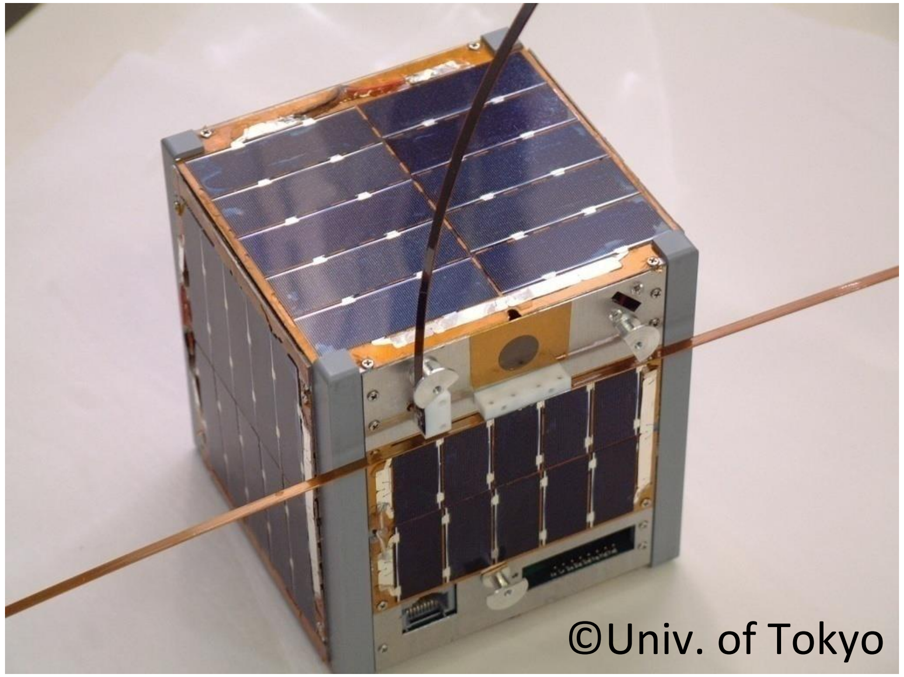
Autonomy and Intelligence for Space Systems


Micro/nano/pico
-satellites Fleet
Intelligent Space Systems Laboratory
The University of Tokyo
13
Satellites Launched
4
Satellites will be launched soon
18
Years of In-orbit Satellite Operations
120
Students Graduated
@2020
Capacity Building Support Projects
XI-IV (2003)
In operation (17 years)
XI-V (2005)
In operation (15 years)
Education Experiments
PRISM (2009)
In operation (11 years)
MicroDragon (2019)
In operation
Collaborator: VNSC
HODOYOSHI 1, 3, 4 (2014)
In operation (6 years) Collaborator: Axelspace, NESTRA
Earth Observation
Strix-α (2020)
In operation
Collaborator: Synspective
Nano-JASMINE
Awaiting launch
Collaborator: NAOJ
Space Science
TRICOM-1R (2018)
End of operation (0.5 years)
Collaborator: JAXA
RWASAT-1 (2019)
In operation (1 years)
Collaborator: Rwanda
PROCYON (2014)
End of operation (3 years)
Collaborator: JAXA
Deep Space Missions
EQUULEUS
will be launched in 2021
Collaborator: JAXA
Technology Demonstration
AQT-D (2019)
In operation (1 years)
Collaborator: UT-SPL
G-Satellite (2020)
In operation
Collaborator: TOCOG, JAXA
Entertainment
Next-Generation 6U CubeSat
under development
Versatile

Example – 1U CubeSat "XI-IV"

Mission: Pico-bus technology demonstration in space, Camera experiment
Developer: University of Tokyo
Launch: ROCKOT (June 30, 2003) in Multiple Payload Piggyback Launch

Size	10x10x10[cm] CubeSat
Weight	1 [kg]
Attitude control	Passive stabilization with permanent magnet / damper
OBC	PIC16F877 x 3
Communi-cation	VHF/UHF (max 1200bps) (amateur frequency band)
Power	Si solar cells for 1.1 W
Camera	640 x 480 CMOS
Life time	Already over 18 years



Captured Earth images are distributed to mobile phones

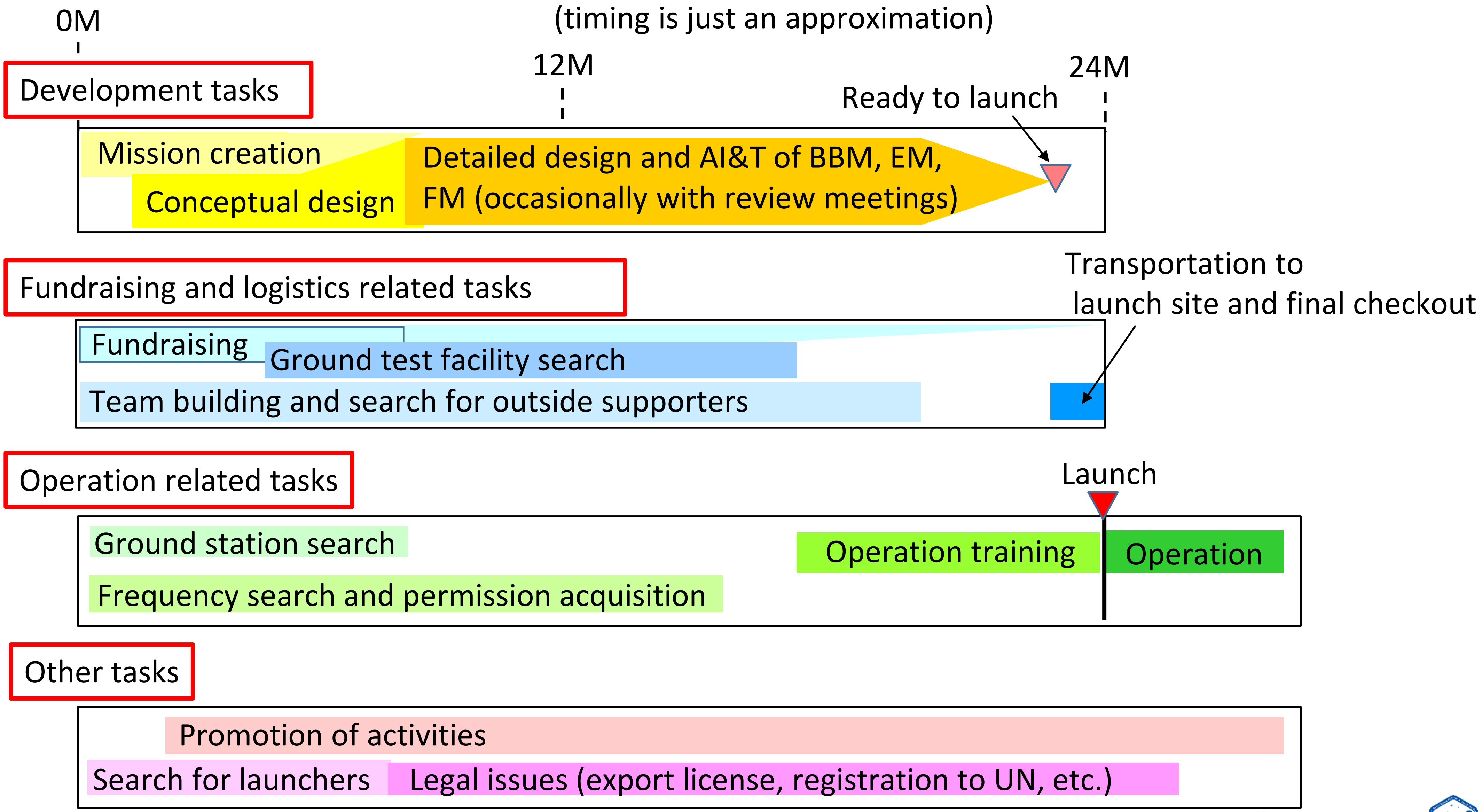
Contents

1. Overview of the satellite development process
2. Create a good mission !
3. System level design
4. Subsystems and teaming
5. Flow of satellite development and review meetings
6. Ground test and feedback
7. Launch arrangement and interface control
8. Ground station and satellite operation
9. Conclusions

1. Overview of the Satellite Development Process

Sequence of Satellite Development

If you want to develop 1U CubeSat within two years, ...

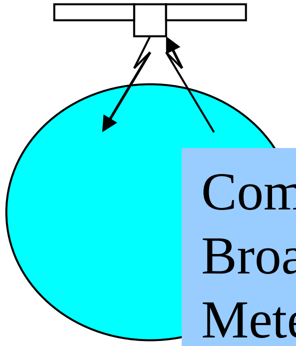


2. Create a good mission!

1. Why do we use space ?

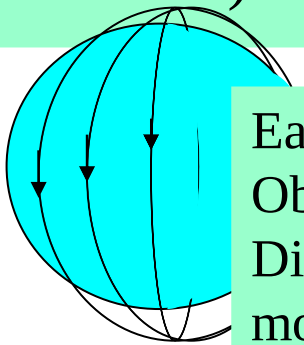
Features of space which lead to space utilization

①Providing 3 D View



Communication, Broadcasting, GPS, Meteorological, Earth Observation

②High Speed Earth Coverage (5-8 km/s)



Earth Observation, Disaster monitoring

③Above Atmosphere

- Space Telescope, Various spectral observations,
- Solar power generation

④Long time μG environment

- New material/medicine
- Life science experiment

⑤Space as Exploration Target

- Observation of Planets, Small bodies
- Particles, Fields, etc.

⑥"Humans in Space" (travel)

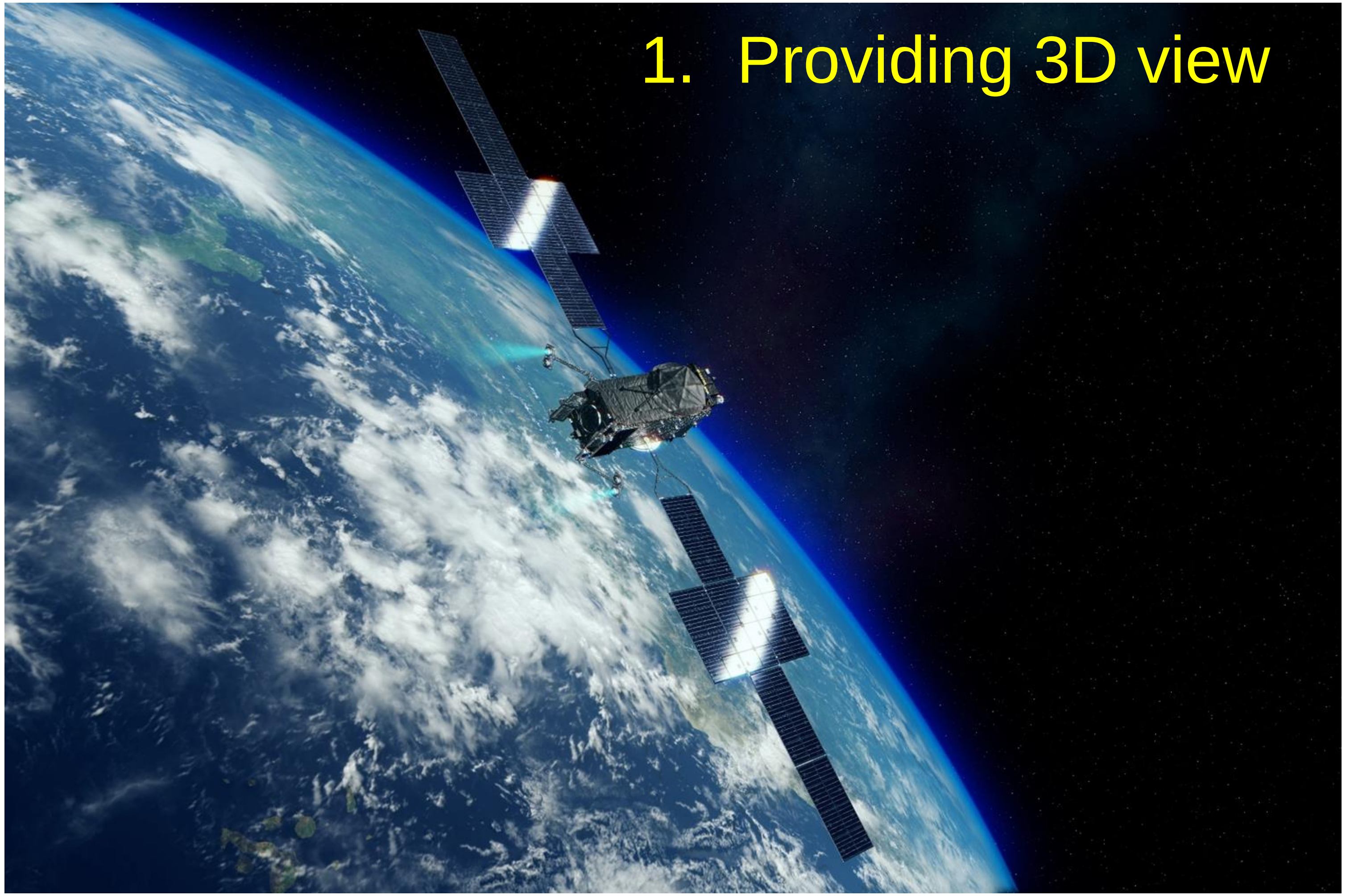
⑦⑧---- Waiting for other new ideas !

Practice 1

- Which special features (from 1-6) are utilized in the satellites in the following slides?

1. Providing 3D view
2. High speed coverage of the Earth
3. Staying above the atmosphere
4. Obtaining long time micro-g environment
5. Space as an exploration target
6. Human existence in space
7. Others

Communication/broadcasting satellite

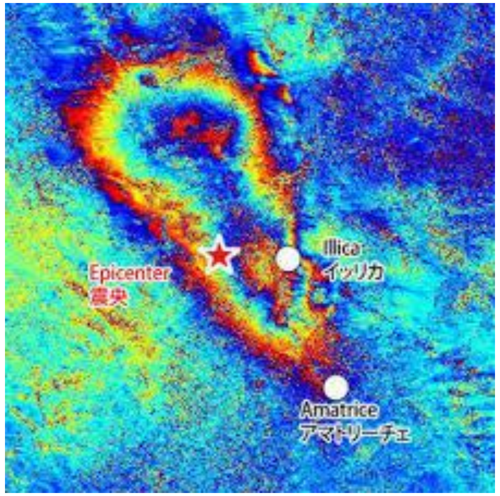


ETS-9 (Engineering Test satellite) ©JAXA

Synthetic Aperture Radar (SAR)

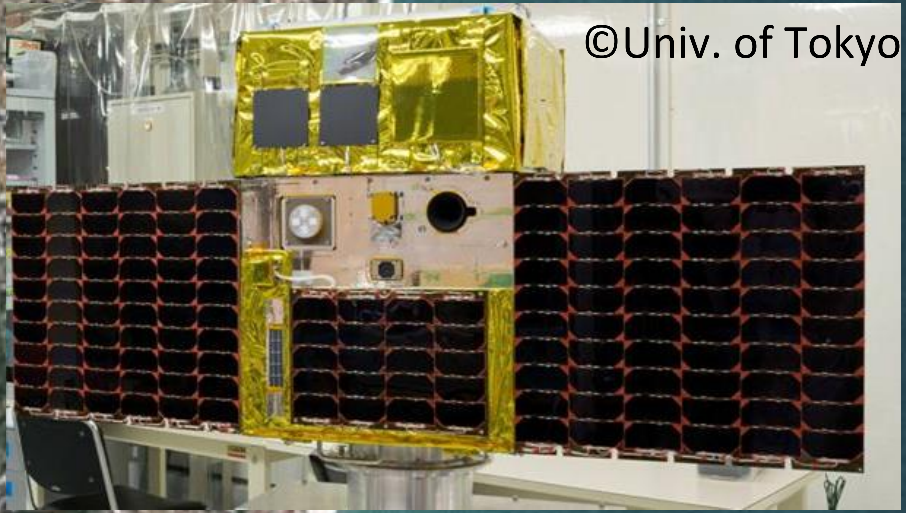
ALOS-2

1. Providing 3D view
2. High speed coverage of the Earth

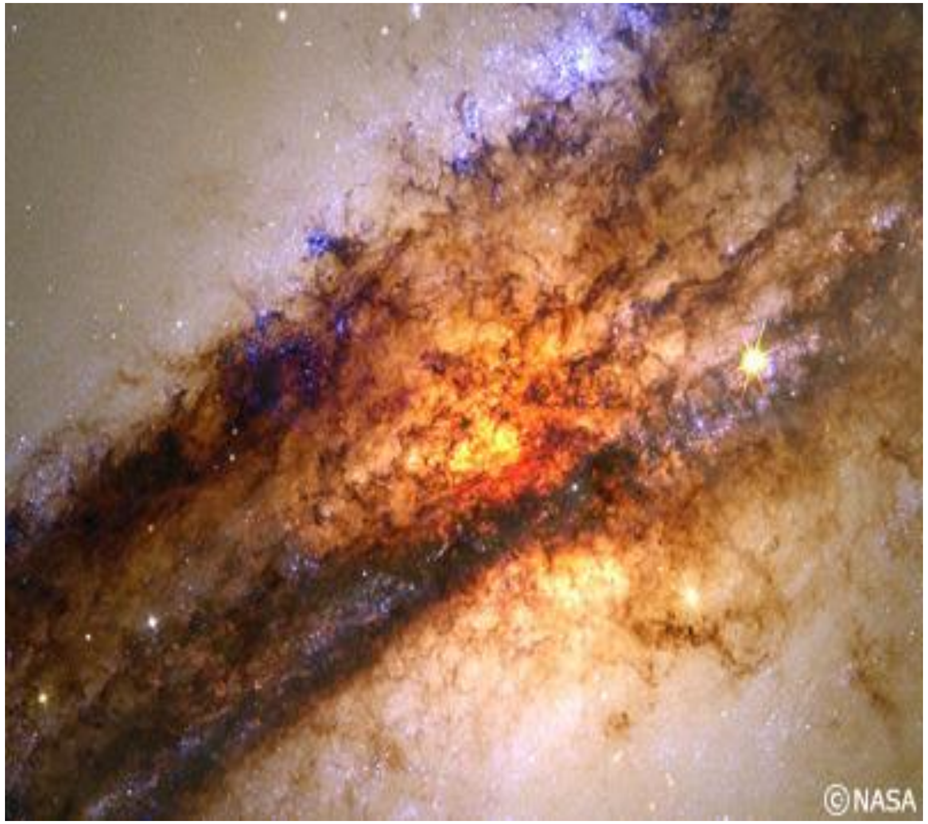


1. Providing 3D view
2. High speed coverage of the Earth

Hodoyoshi-4
Earth
Observation
Satellite



Hubble: Space Telescope

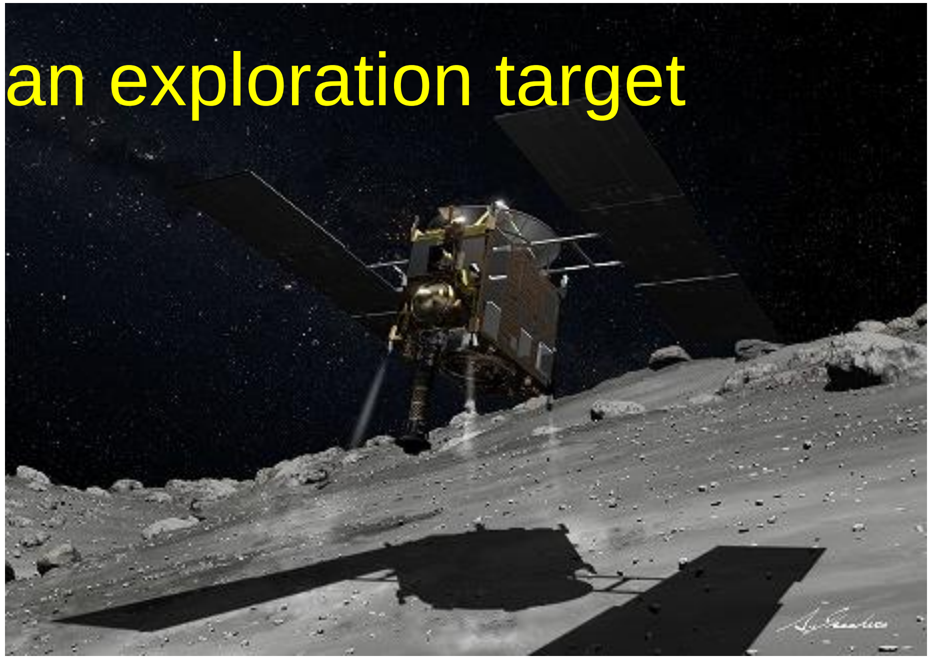


Hubble Space Telescope (1990～)

Deep Space Exploration Probe

5. Space as an exploration target

©JAXA



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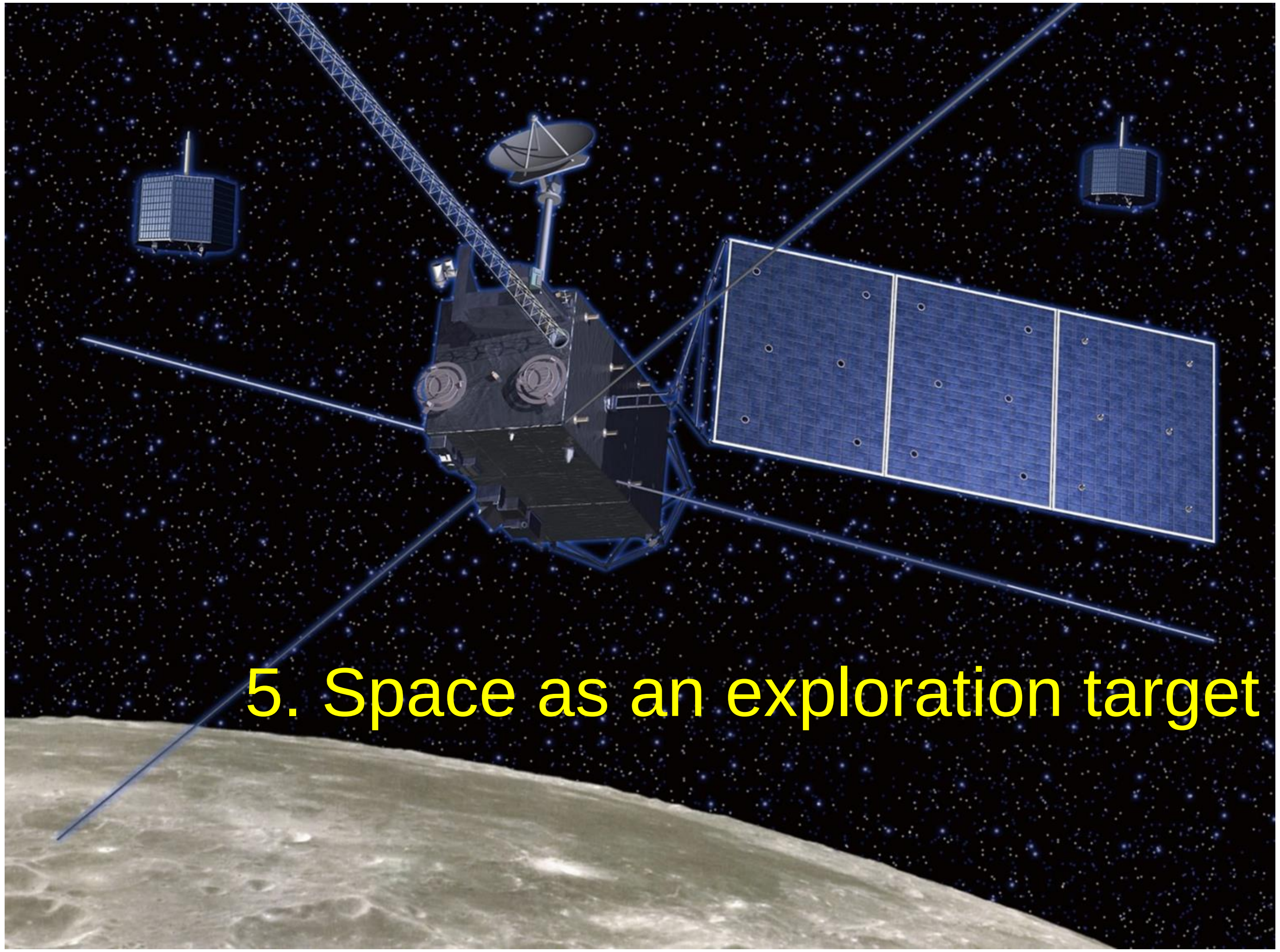
“HAYABUSA（MUSES-C）”

Launched in 2003, Returned 2010

“Sample return” from asteroid “Itokawa”

Lunar Exploration Satellite



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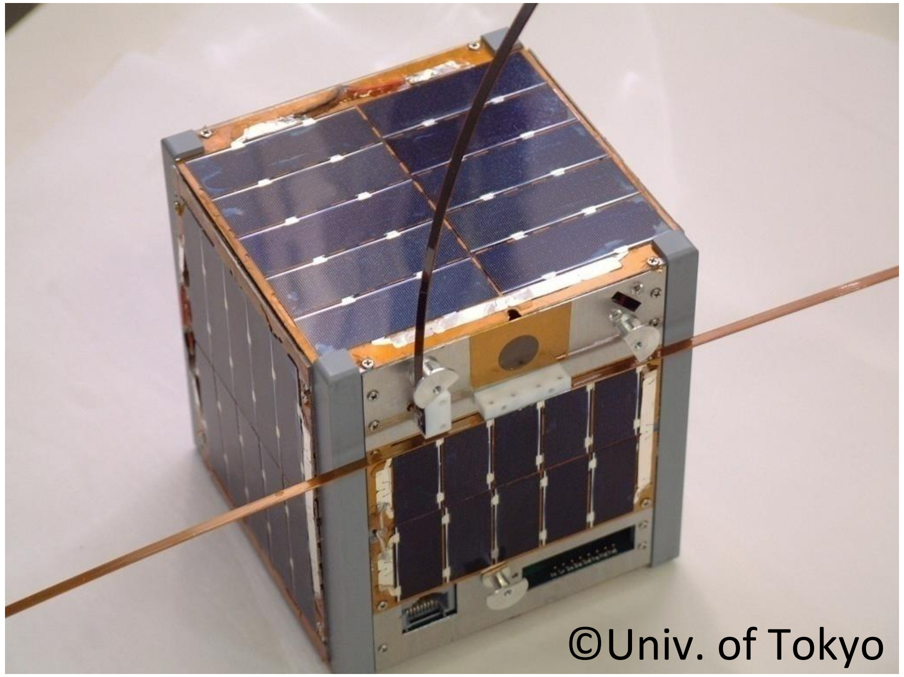
Kaguya

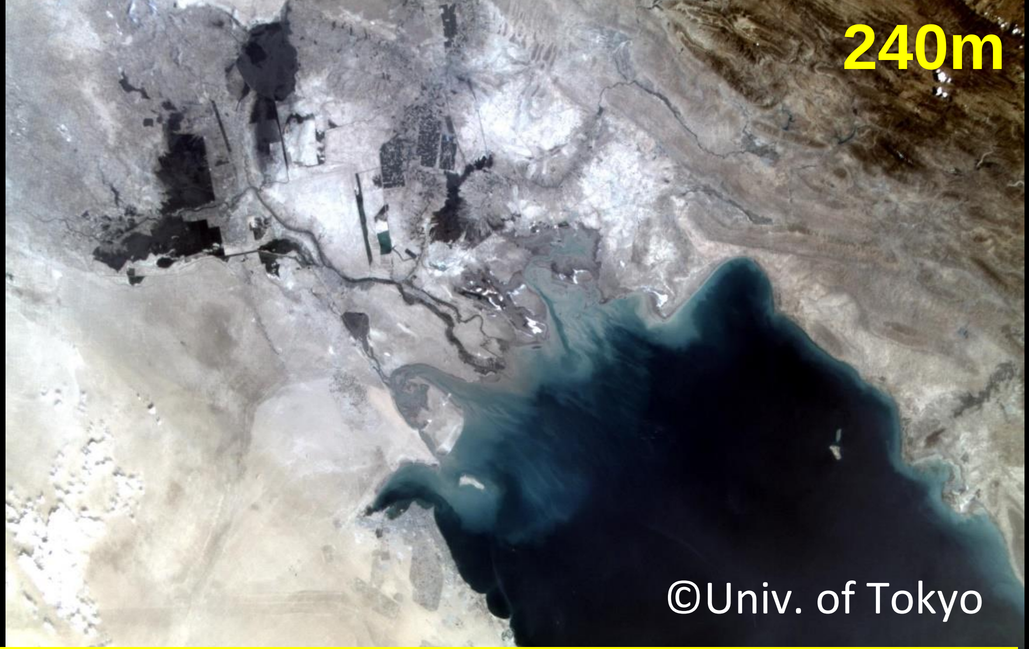
What kind of missions are possible for a CubeSat?



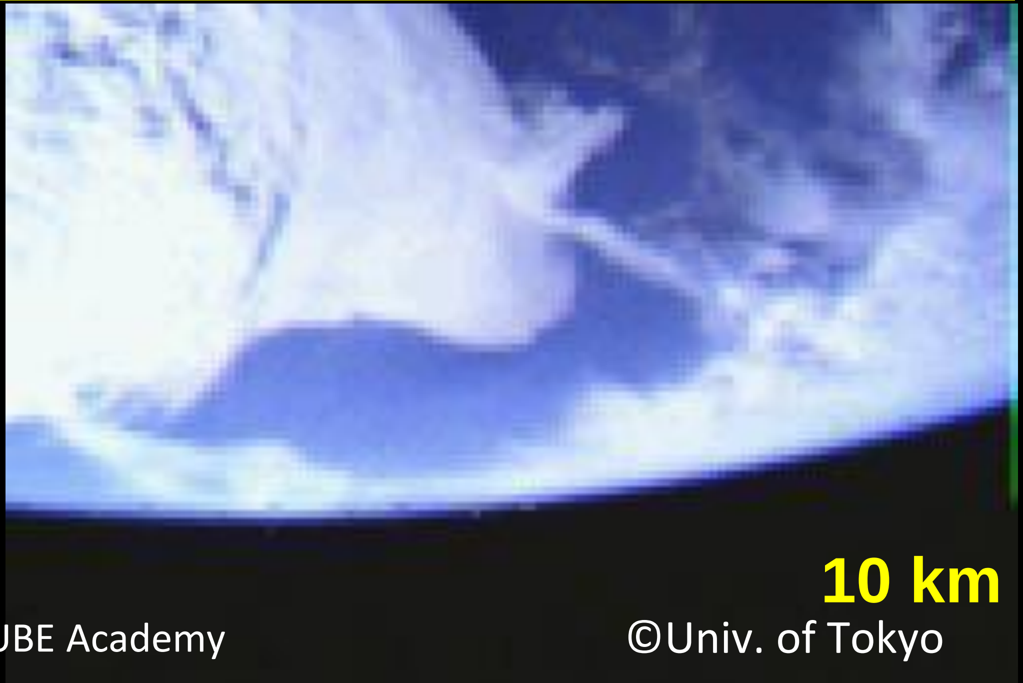
Size: 10cm x 10cm x 10cm   < around 1kg
Orbit: near ISS orbit if deployed from ISS

Example Missions for CubeSat (1)

- Earth observation with onboard camera
  - What is your observation target ?
    - Agricultural field, disaster, land usage, sea shore, houses…..
  - What resolution is required ? (5m, 10m, 100m ?)
    - Limitation: resolution is strictly limited by a small aperture size
  - Wavelength: red, green, blue, red edge, near infrared….
- Star observation with onboard camera
  - Limitation: stars are dim and a long exposure time is necessary, which requires high attitude stability for a long time
- Other sensing from space or in-situ observation
  - Special sensors are required: collaboration with researchers of the Earth, atmosphere, space science, etc.
  - In-situ plasma, particle, magnetic field, atmospheric drag….



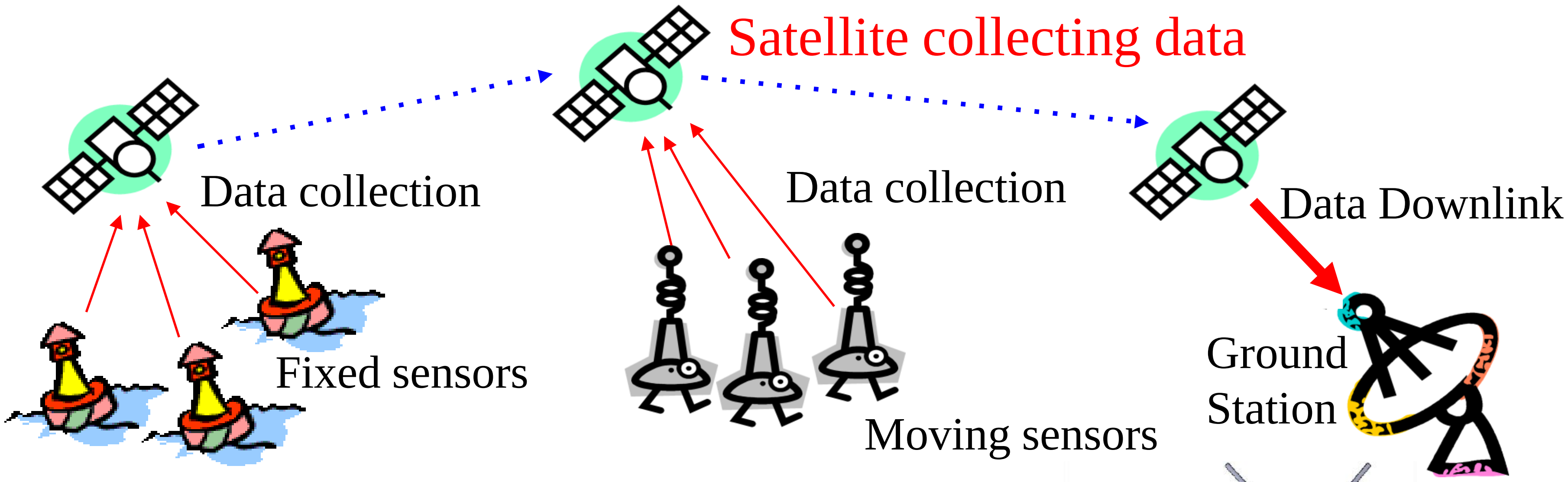
What spatial resolution do you need for your mission ?



Example Missions for CubeSat (2)

- Communication with the ground
  - From the ground to the satellite
    - Risk information, personal data, health data, disaster related information. (effective where there is no mobile phone network)
    - Limitation: data rate is limited by power, and antenna size
  - From the satellite to the ground
    - Broadcasting messages such as warning signals, education, etc.
  - Message relay: uplink, carry and downlink message
- Experiment inside a CubeSat
  - Experiment using microgravity or other space environment, etc.
    - How to automatically do an experiment, record and downlink to the ground?
- Technological experiments or demonstrations
- Others

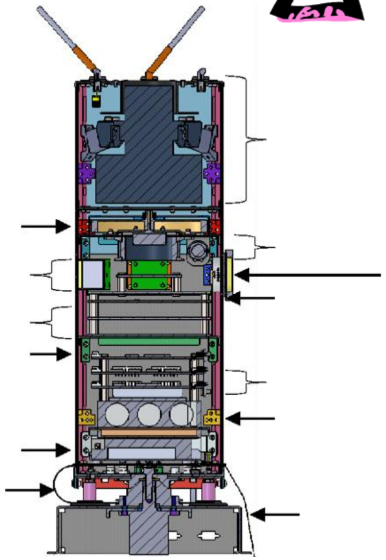
Example) IoT Mission



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>**

8 - 20 mW RF power, low data rate (300bps) transmission was successful.



3kg TRICOM-1R

Important Tactics for Mission Creation

- Do not aim at high level missions
  - Aperture size and focal length limit spatial resolution
  - Uplink/Downlink communication speed is limited
- Should be installed into a 10 cm cubic shape before release from the rocket
  - Antenna and other appendages should be initially stowed and deployed after release from the rocket
  - Generated power is around 1 - 2 W on average (1U)
- “Satellite bus system functioning” in itself is a good mission if it is your first project

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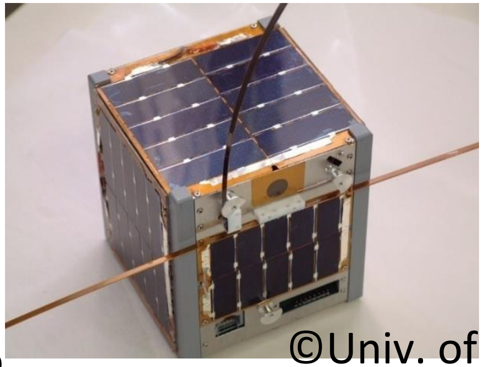

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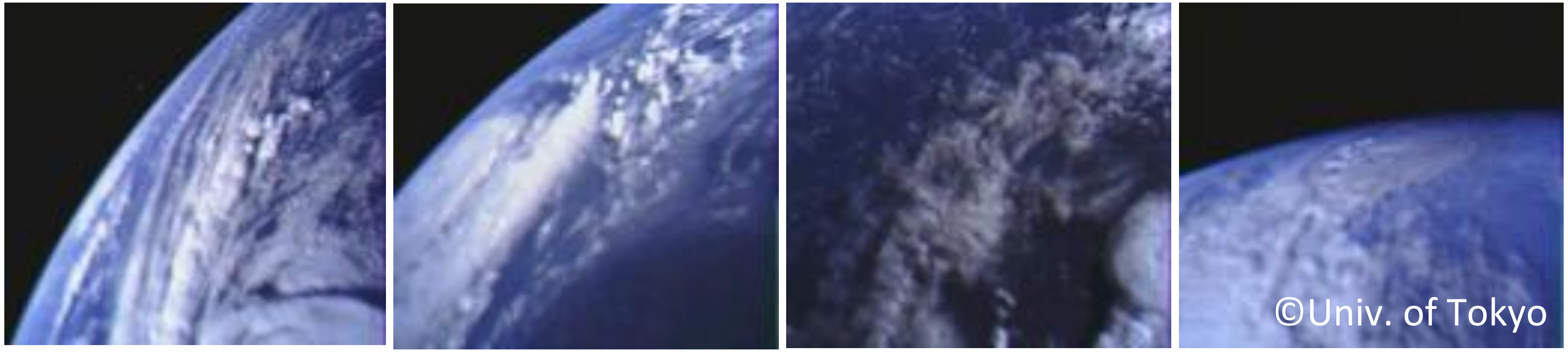
Example) CubeSat "XI-IV" Missions

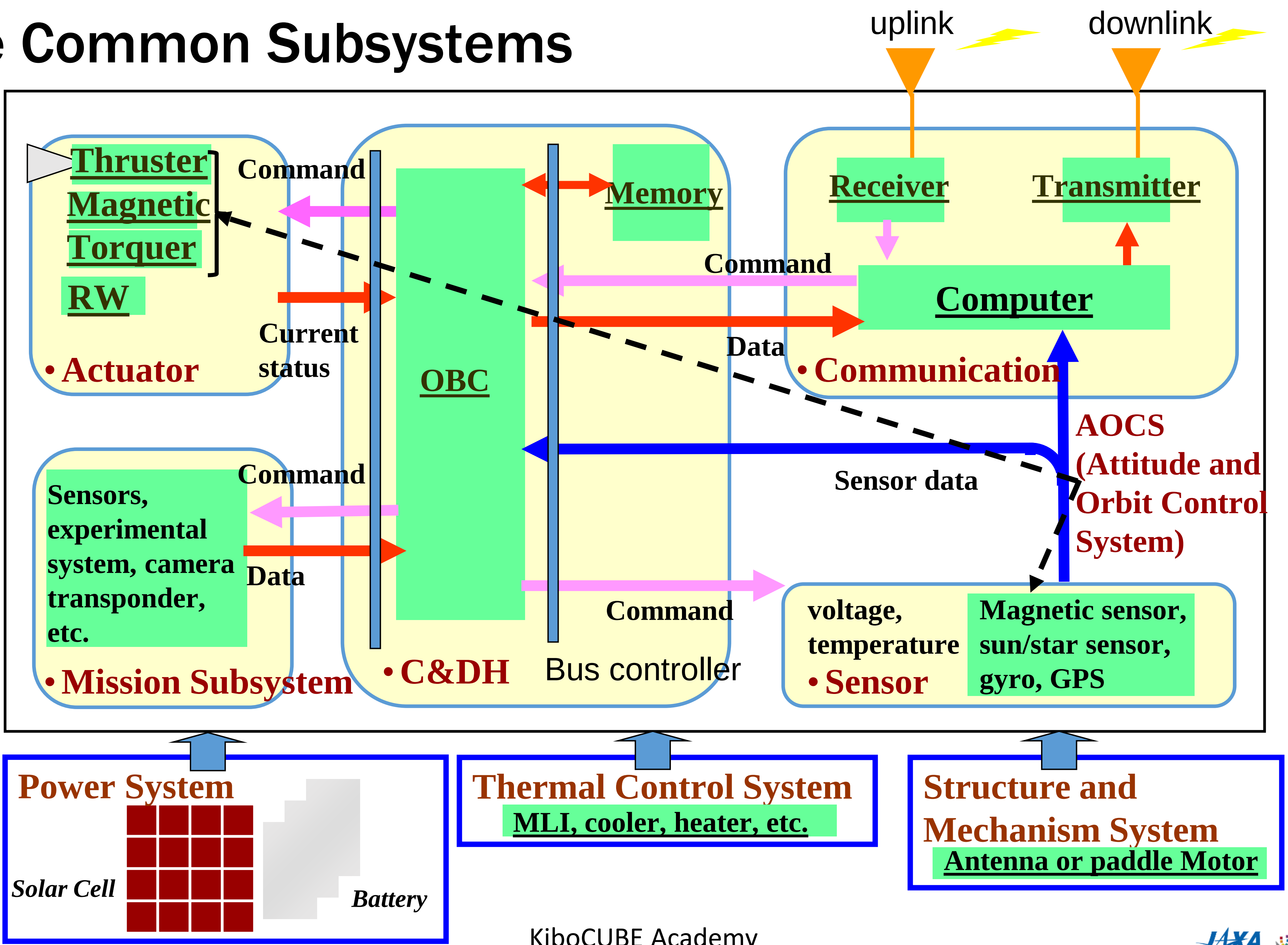
- Realizing satellite bus functions for a certain period
  - The satellite functioning as designed
  - Making it survive in a space environment (for minimum half a year)
  - Communication using an amateur radio frequency
- Capturing and downlinking Earth photos
  - XI-IV captured as many photos as possible and only photos which have Earth images were stored and downlinked



  - 1200 bps communication speed requires 3 - 4 days to downlink 1 photo

3. System Level Design

Satellite Common Subsystems



Breakdown of mission requirements

- Attitude control subsystem
  - Free motion
  - Gravity gradient, passive magnetic control
  - Three axis control: on-board antenna or camera is to be directed towards the some location on Earth
    - accuracy of attitude determination, orientation control and stability
- Communication subsystem
  - How much data should be downlinked to the ground per day decides the downlink communication speed
- Power subsystem
  - Maximum and average power requirement should be satisfied
- Thermal control subsystem
  - Temperature control for each component to be in allowable range
- Structure and mechanism subsystem
  - Should endure launch load, with deployment mechanism if required

System Level Design: "Budgeting"

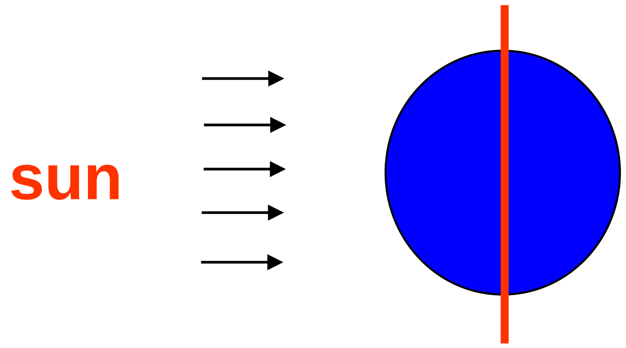
- Input to weight/size/power budgeting -

Equipment	weight (g)	Size (mm)	Power (mW)	Temperature (℃)
Transmitter	90	80x80x10	800	-10 ～ 50
Receiver	80	80x80x10	100	-10 ～ 50
Antenna	30	80x80x8	500	-10 ～ 50
Computer	100	80x80x10	200	-10 ～ 50
Power Dist.	120	40x40x10	50	-10 ～ 50
Battery	150	90x90x10	-	-5 ～ 40
Solar cells	80	50x30x1	-	-20 ～ 100
Wheels	100	20x20x30	500	-10 ～ 50
Mag. sensor	100	20x20x10	200	-10 ～ 50
Mag.torquer	150	Φ10x50	1000	0 ～ 30

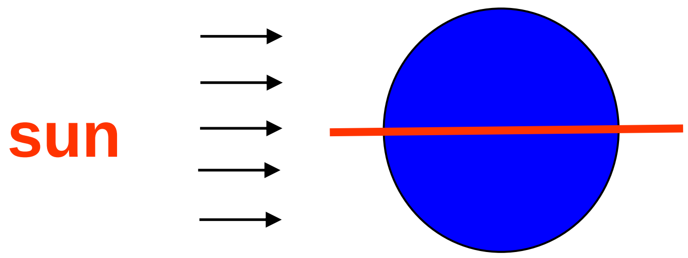
Power Budgeting (1)

Calculate power generation considering the orbit of your satellite

- Estimate eclipse percentage from the relationship between orbit and sun direction
  - In eclipse period, battery is used to supply power
- Calculate the average power generation based on orbit information, attitude control strategy, and solar cell implementation design



Almost 0 % eclipse

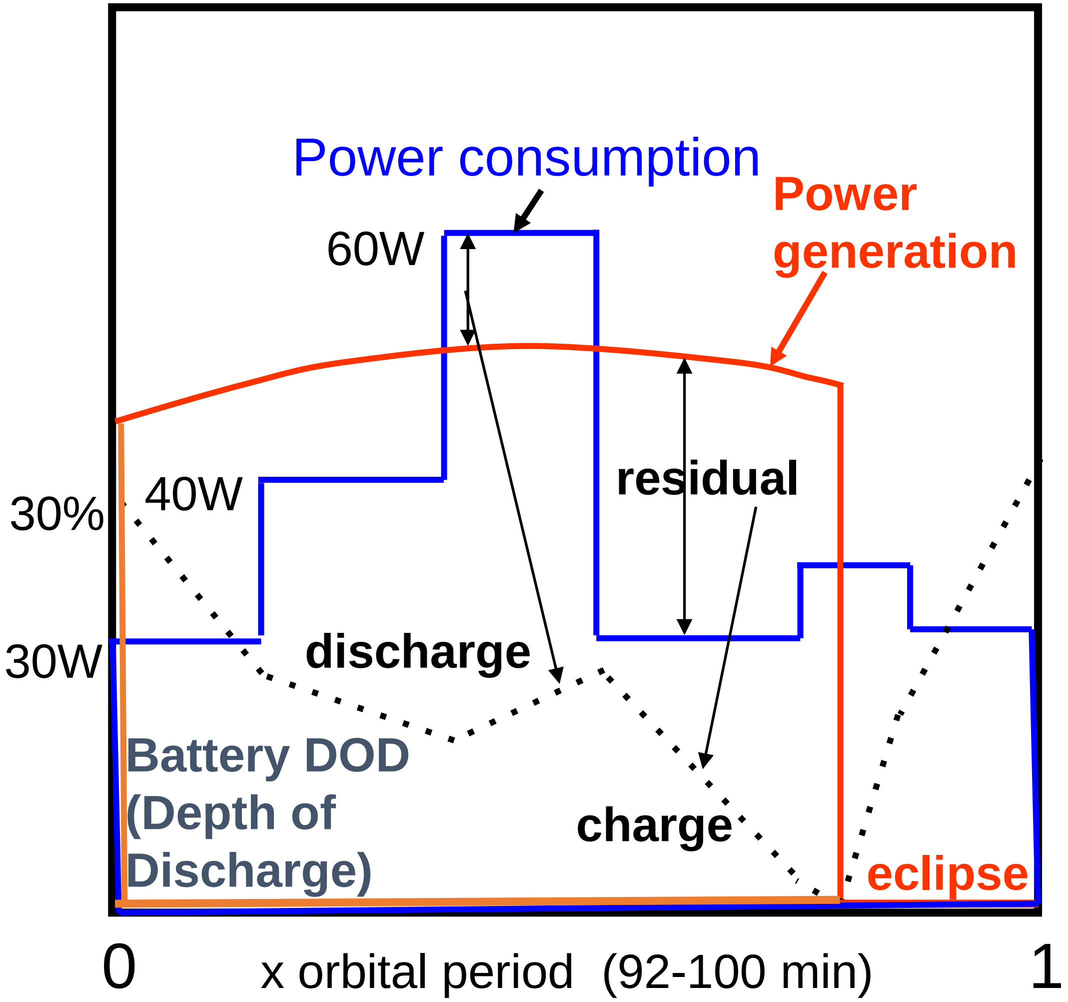


40 – 48 % eclipse

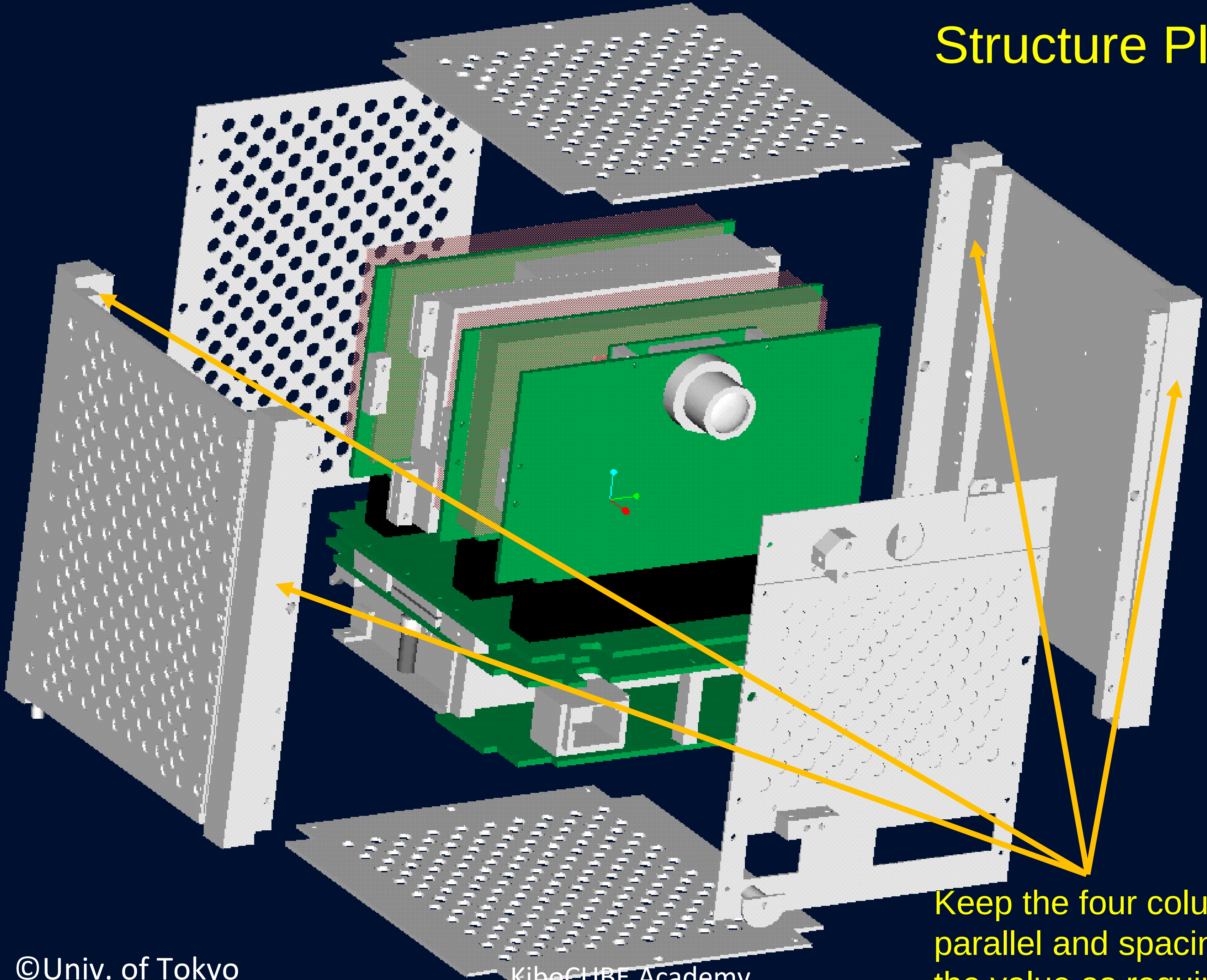
Power Budgeting (2)

Balance power generation and consumption

- Power consumption = power generation in one orbital period
  - Solar cells sizing (efficiency: 16～30 %)
  - Satellite attitude with respect to the sun
- Battery to provide additional power
  - Battery sizing to make maximum DOD (Depth Of Discharge) be about 30 %



Structure Plan



Keep the four columns exactly parallel and spacing should be the value as required

4. Subsystems and Teaming

Satellite Subsystems

- Mission subsystem
- Command & Data Handling (C&DH)
- Communication (COM)
- Electric Power (EPS)
- Attitude Determination and Control (ADCS)
- Structure and Mechanism
- Thermal Control
- (Special subsystems required for your mission)

- Ground Station

Teaming

- Based on subsystems
  - Ex) assigning two subsystems to each member
- Based on administrative roles:
  - Project Manager (PM), Sub-manager (Sub-PM)
  - Budget management
  - Parts/components search and purchase
  - Documentation and data control (Web, ICD(Interface Control Document)….)
  - External relationships & promotion
    (getting permission, regulations, legal issues, seeking funds, etc.)
  - Consultation Team
    - External experts on electronics, communication, structure, ground test, etc.

5. Flow of Satellite Development and Review Meetings

Water Flow Project Management

Mission Creation

System level design

Breadboard Model (BBM) Phase

Trial-and-error of detailed design

PDR (Preliminary Design Review)

Check feasibility of realizing the mission

Engineering Model (EM) Phase

Assuring functions in a space environment

CDR (Critical Design Review)

Finalize design and trigger FM fabrication

Flight Model (FM) Phase

Fabrication as designed

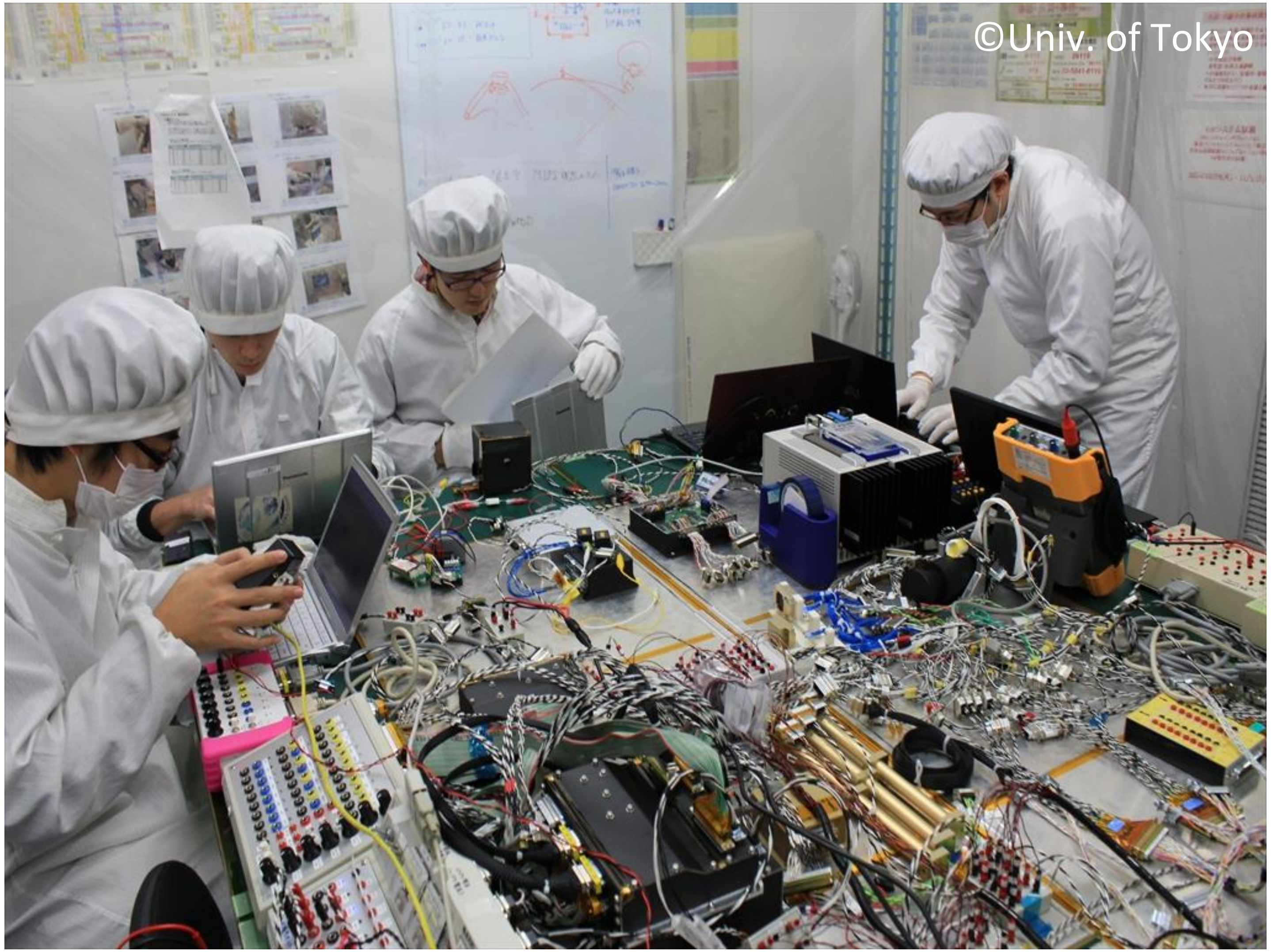
LRR (Launch Readiness Review)

Check completion of FM to be ready for launch

Launch & Operation

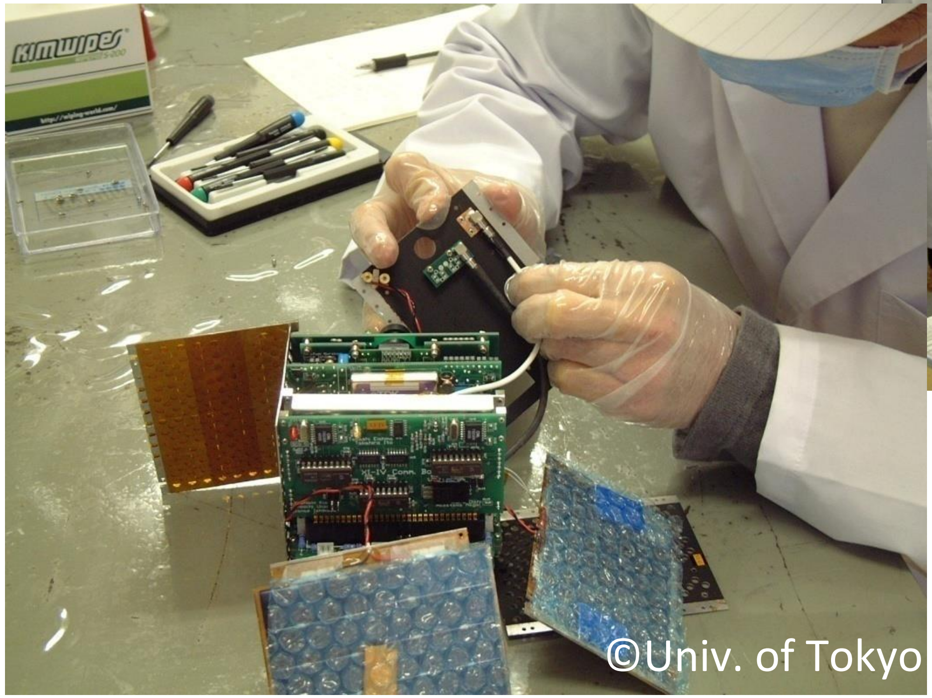
Table-Sat Test

"Table-sat" test assures proper functionalities



FM Integration in Clean Room

Mounting solar cells on the flight model in a clean booth



Final Integration Procedure

6. Ground Tests and Feedbacks

Usually Required Ground Tests

Mission Creation

System level design

Breadboard Model (BBM) Phase

Trial-and-error of detailed design

Radiation tests
Simple function tests (table sat)

Engineering Model (EM) Phase

Assuring functions in a space environment

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

Flight Model (FM) Phase

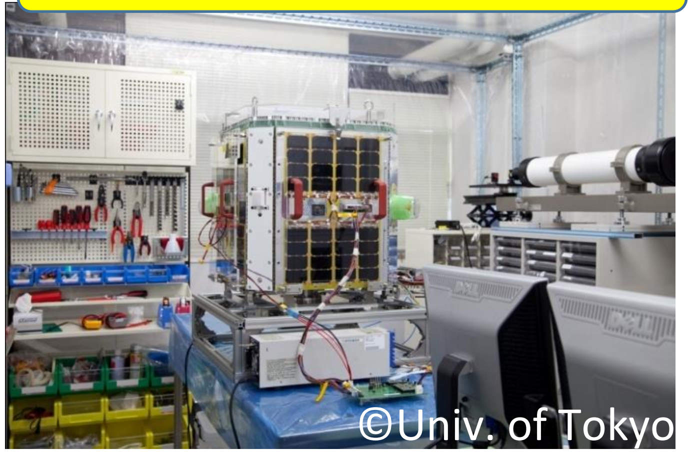
Fabrication as designed

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

Launch & Operation

Satellite Development & Operation Facilities

Clean Booth (class100,000)



Vibration Table (25g rms)

Thermal bath
(-70 ～100 ℃)

Thermal Vacuum Chamber

UHF/VHF/S-band Ground Station Antenna

- Solar Simulator
- RF test room
- Vacuum Chamber

Find external facilities if you don’t have them!

Example) CubeSat “XI-IV” Development

1.8 years of Development

2000: 8, 9, 10, 11, 12 | 2001: 1, 2, 3, 4, 5

Mission Creation

System Level Design

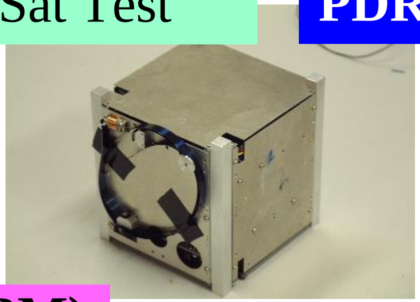
Radiation Table-sat Test

XI-I（BBM)

Trial and Error

Table Sat Test

PDR



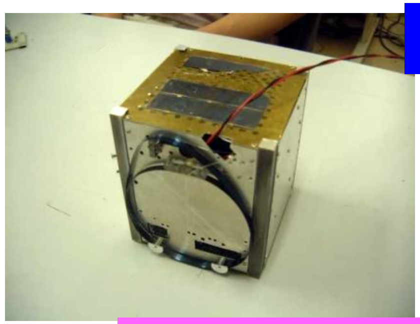
XI-II (BBM)

6, 7, 8, 9, 10, 11, 12 | 2002: 1, 2, 3

Long Range Comm. Test

Vibration

Thermal Vacuum



XI-III (EM)

CDR

XI-IV,V(FM)

Thermal

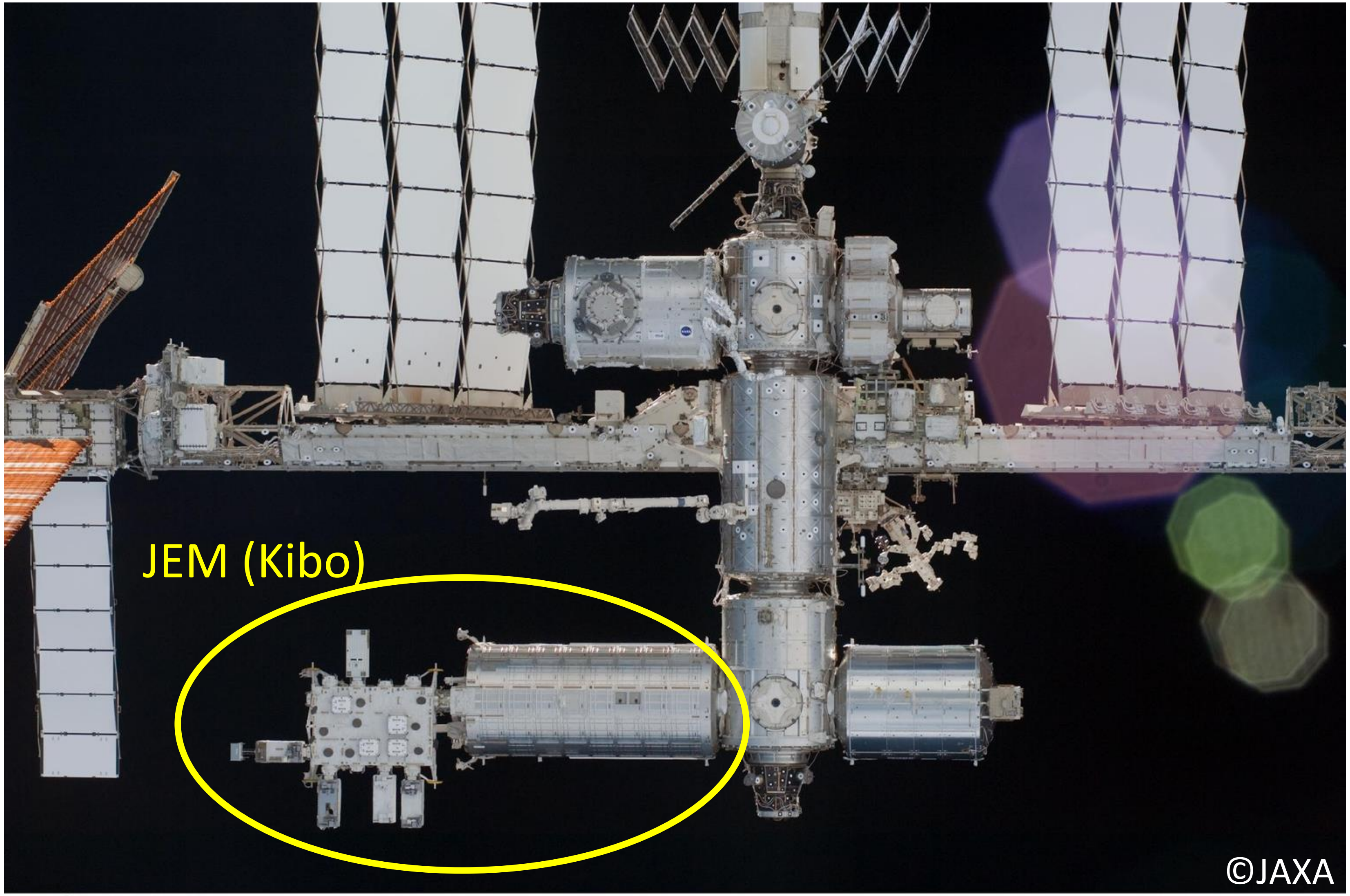
Vacuum

Operation training

LRR

7. Launch Arrangement and Interface Control

Deployment from ISS



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Considerations in Launch Interface Control

- CubeSats will be deployed from rockets or the ISS, and “a POD” is used for launch interface (for ISS case “J-SSOD”)
- The fabricated CubeSat shape and size should perfectly match with the POD internal size
  - The specifications of POD will be informed by the launch provider (for ISS case, JAXA)
  - The CubeSat’s four vertical columns should be parallel and have exactly the same spacing as required
- “Cold Launch”: CubeSat is switched off during the launch and should be switched on automatically after release from POD
  - You should prove that your CubeSat will not be turned on during this period

Safety Requirements for Deployment from ISS

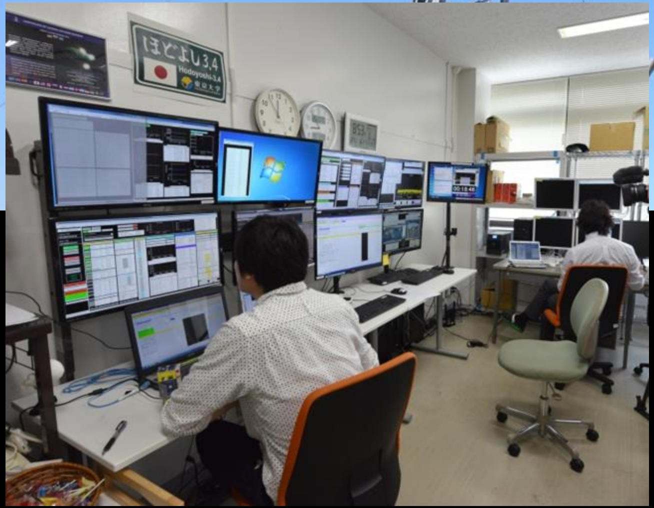
Your CubeSat should follow various rules.

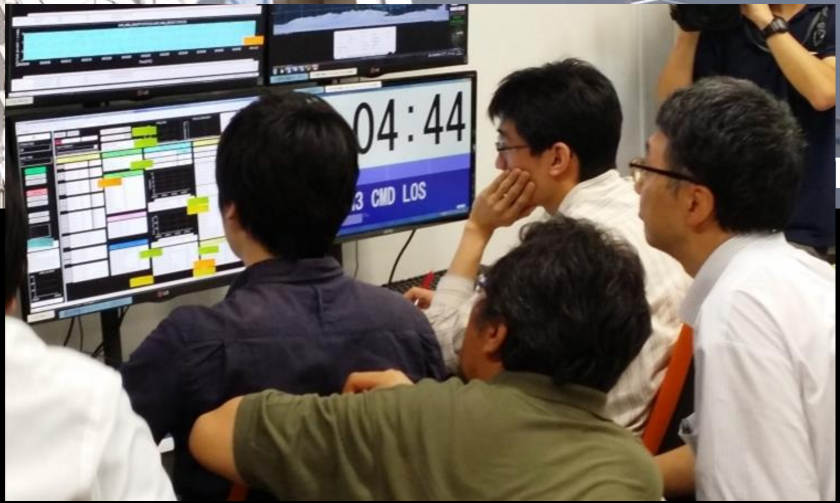
- Structure strength and rigidity
  - Tolerant against acceleration and vibration load, etc.
  - Fundamental frequency has to be over 60 Hz
- Size and weight
  - Should match the J-SSOD size and weight requirement
- May have to wait a long time before launch
  - Waiting time may be as long as several months to one year
- Environmental conditions
  - Should be tolerant against given pressure change, temperature and humidity environment, etc.
- Many other rules will be instructed by the launch provider
  - Proof should be provided from simulations, ground tests and/or fit check etc.
- Please refer to JEM Payload Accommodation Handbook

8. Ground Station and Satellite Operation

Find a ground station !

Tokyo





Preparations for the Ground Operation

- Frequency permission has to be obtained before release from the ISS or a rocket, which requires more than 1.5 – 2.0 years of negotiation with your authority of communication, and amateur telecommunication community.
- Ground station (UHF, VHF or S-band, X-band) is required for satellite operation, which you can build, or can even rent/borrow from companies or a space agency, etc.
  - Yagi-antenna (cheap but low gain), parabolic antenna, etc.
  - Modulator/demodulator, low noise amplifier, etc.
- Command/telemetry should be defined by the satellite developers and software should be coded on the ground station's computer
  - Can expect 6～8 times of 5～12 minutes operations per day if deployed from ISS
  - Should make operational plans (check items, commands, etc.)
  - Preparation is very important as the operation period is very short

9. Conclusions

Keep these in mind!

- Create interesting, yet achievable, missions considering your skill level, satellite size, and available resources
- Conduct system level design to define the subsystem specifications with weight, size, and power budgeting
- Teaming should be well designed considering the expertise of your team members
- Follow a “water flow” type of project management with review meetings and various ground tests, in order to assure proper functionality of your satellite in space
- Make appropriate design of your satellite’s interface with the deployment system (for ISS case, J-SSOD)
- Preparations such as finding a ground station and frequency permission are required in parallel with satellite development

Thank you very much.

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