

# ***KiboCUBE Academy***

***Live Session #1-2***

## **CubeSat Launch and Operation**

Hokkaido University

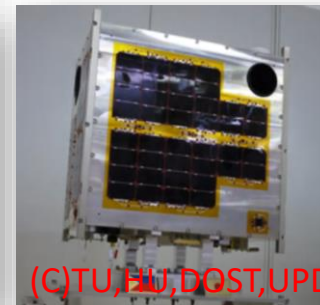
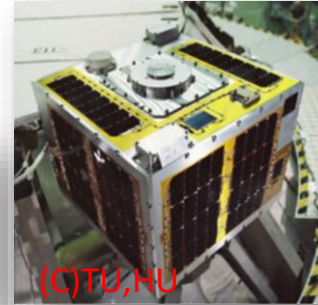
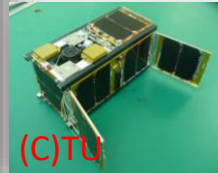
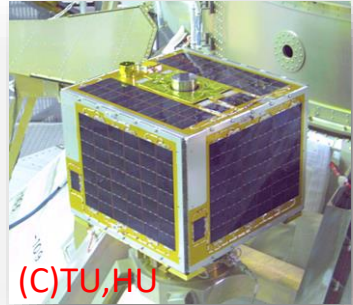
Division of Mechanical and Aerospace Engineering

Associate Professor Dr. Yuji Sakamoto

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>





## Yuji Sakamoto, Dr.

### Position:

2006 - Assistant Professor (-2015), Associate Professor (2015-)  
Department of Aerospace Engineering, Tohoku University

2021 - Associate Professor

Division of Mechanical and Space Engineering, Hokkaido University

TU = Tohoku University

HU = Hokkaido University

DOST = Department of Science and Technology, Philippines

UPD = University of the Philippines Diliman

### Research Topics:

Design, Assembly, and Evaluation of Micro and Nano Satellites

Satellite Operation and Ground Station Management

1. Introduction to Satellite Operations
2. Satellite Orbit and Mission Lifetime
3. Communication System
4. Ground Station + Virtual Tour 1: Operation Rooms
5. Launch and First Contact
6. Mission Operations + Virtual Tour 2: Command Upload in Real Operation
7. Conclusion



# 1. Introduction to Satellite Operations

# 1. Introduction to Satellite Operations

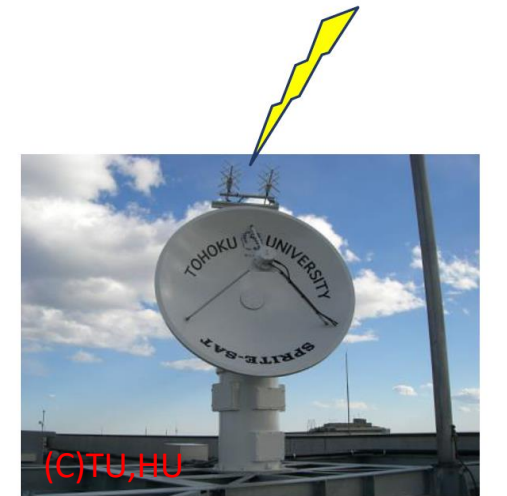
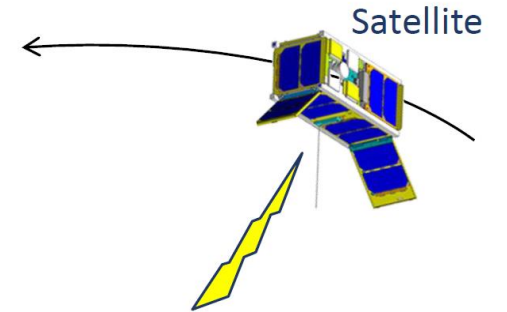


**What do you need to think about for the operation of YOUR satellite?**

© JAXA

# 1. Introduction to Satellite Operations

- Satellites rotate around the Earth, about **14 to 16 times** per day in Low Earth Orbit (LEO)
- About **10 to 12 minutes** per contact from a single ground station, and about **4 passes per day**  
=> data communication time will be **total of 40 to 48 minutes** per day
- Satellite operations **send commands** to satellite from ground stations and **receive telemetries** from satellites
- **BEFORE** the communication, we need to prepare the **daily mission scenario** and the **detailed procedure** of mission tasks.



Ground Station

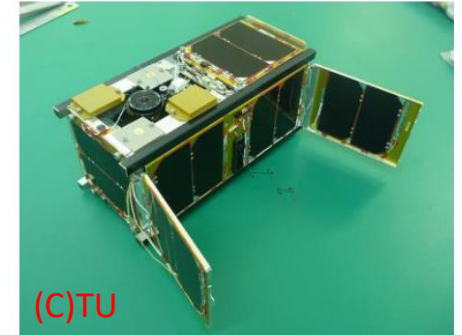
# 1. Introduction to Satellite Operations

- Satellites **cannot be repaired** in orbit after the launch
- We can only communicate with them to **conduct planned missions, solve unexpected problems**
- **Variations of operation scenarios and procedures** need to be **considered and tested BEFORE** the **completion of satellite development**.

=> this is strongly relating to **software concept and design**

=> operations are **not only** a matter of **communication**.

This is relating to other subsystems (**C&DH, ADCS, power, thermal, ...**)



2U CubeSat RAIKO



Satellite Operators

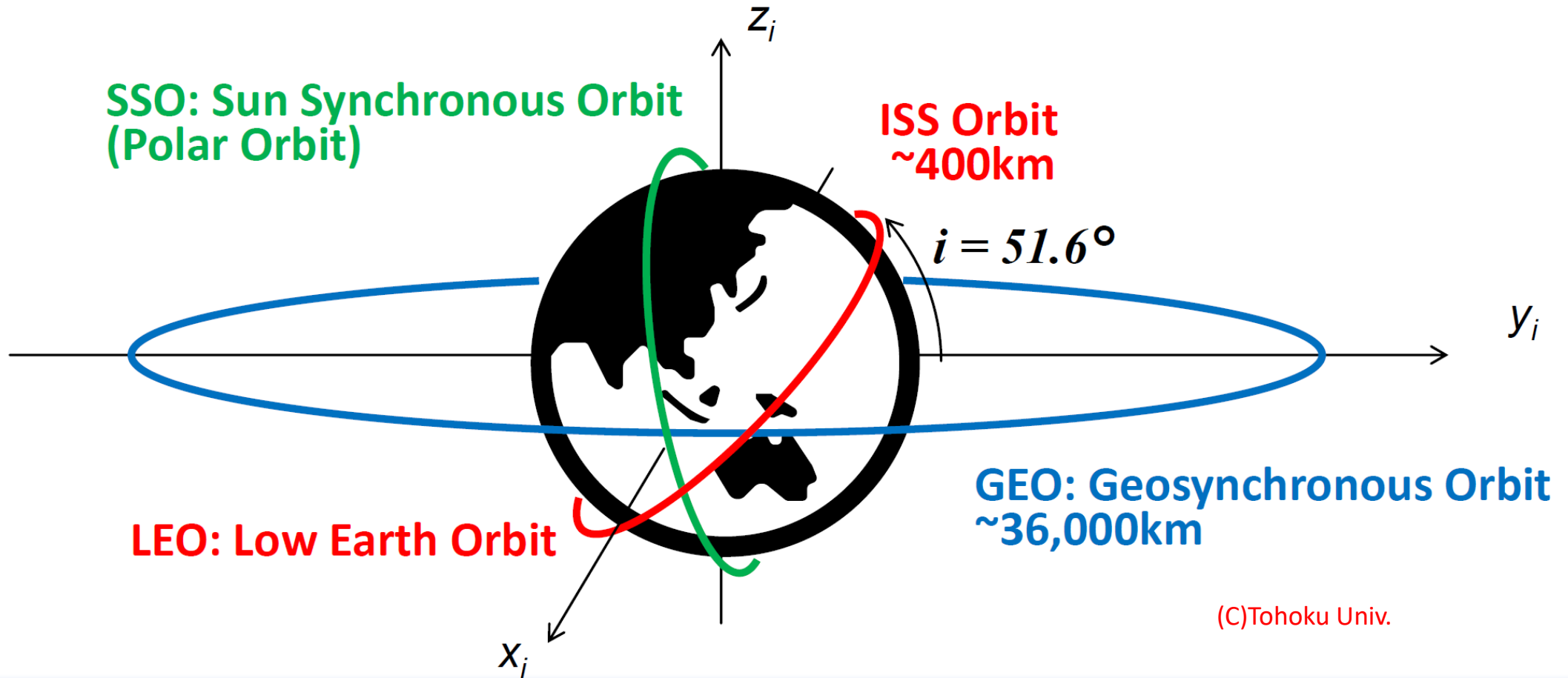


## 2. Satellite Orbit and Mission Lifetime



## 2. Satellite Orbit and Mission Lifetime

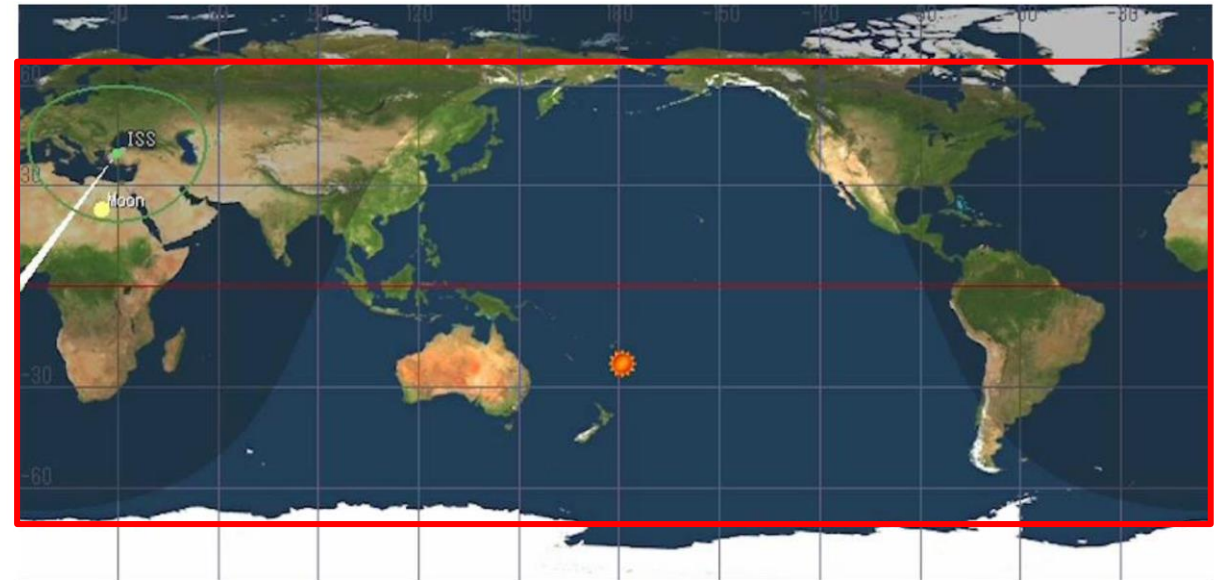
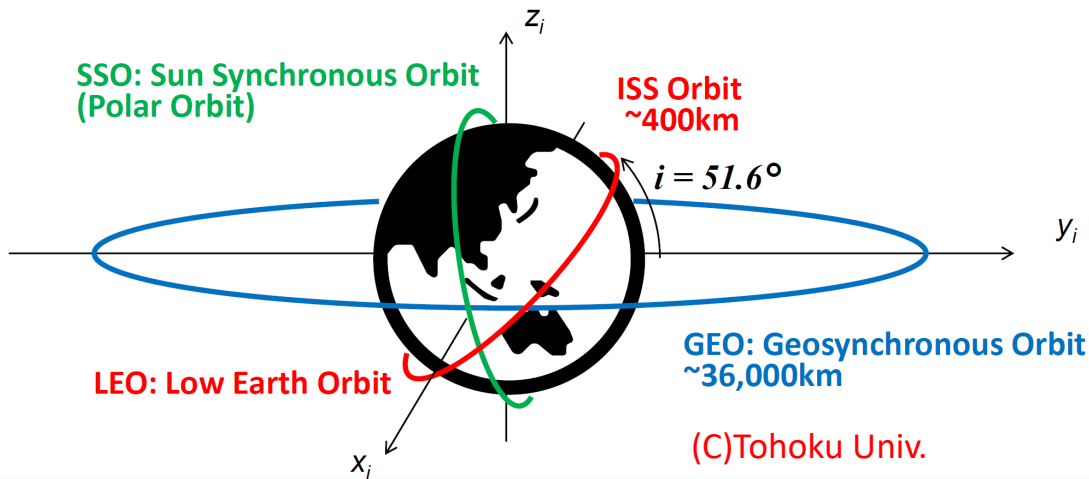
### Type of Satellite Orbits



## 2. Satellite Orbit and Mission Lifetime

### Orbit of International Space Station (ISS)

- ISS orbit (**400km, 51.6 deg**)
- Regions around **Arctic and Antarctica cannot be observed**
- **Solar angle** to orbit is **changing every day**  
=> **affects daily observation timing** to specific locations



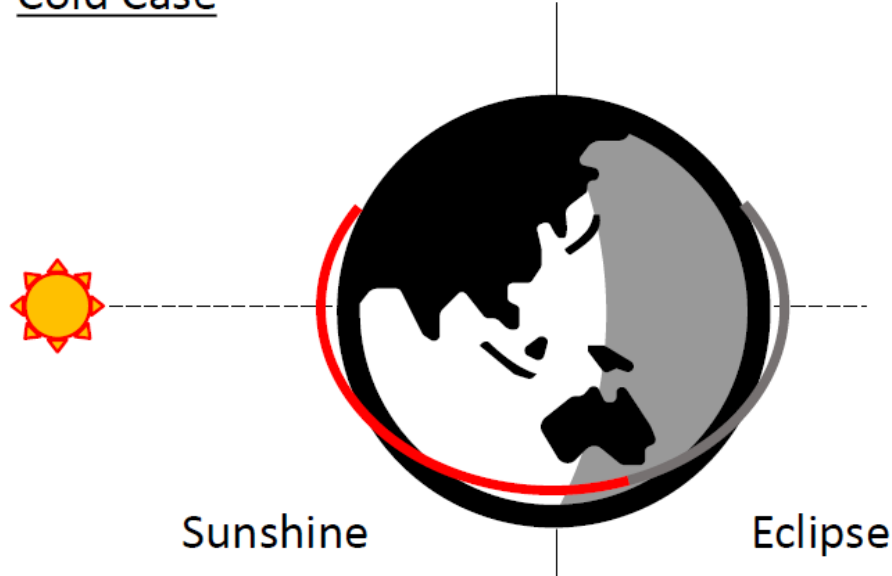
Spheresoft

## 2. Satellite Orbit and Mission Lifetime

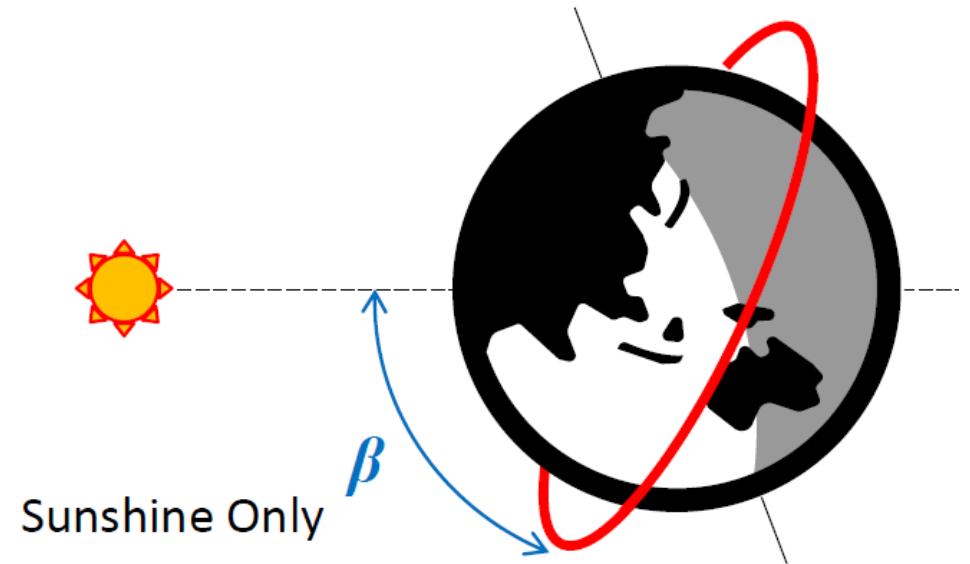
### Influence of the Eclipse

- For ISS released satellites, **all sunshine phase** continues for a few days **around summer and winter**
- **Solar angle to orbit** (= beta angle) can be **more than 70 degrees**.
- **0 deg in Cold Case** can be increased to **40 or 50 degrees in Hot Case**

Cold Case

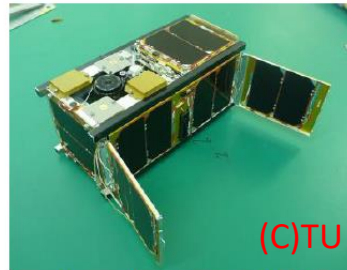
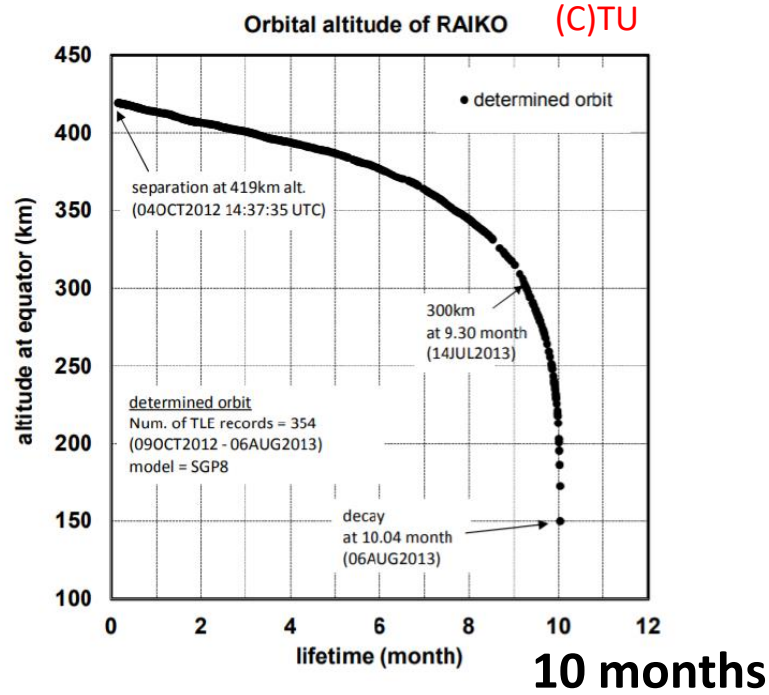
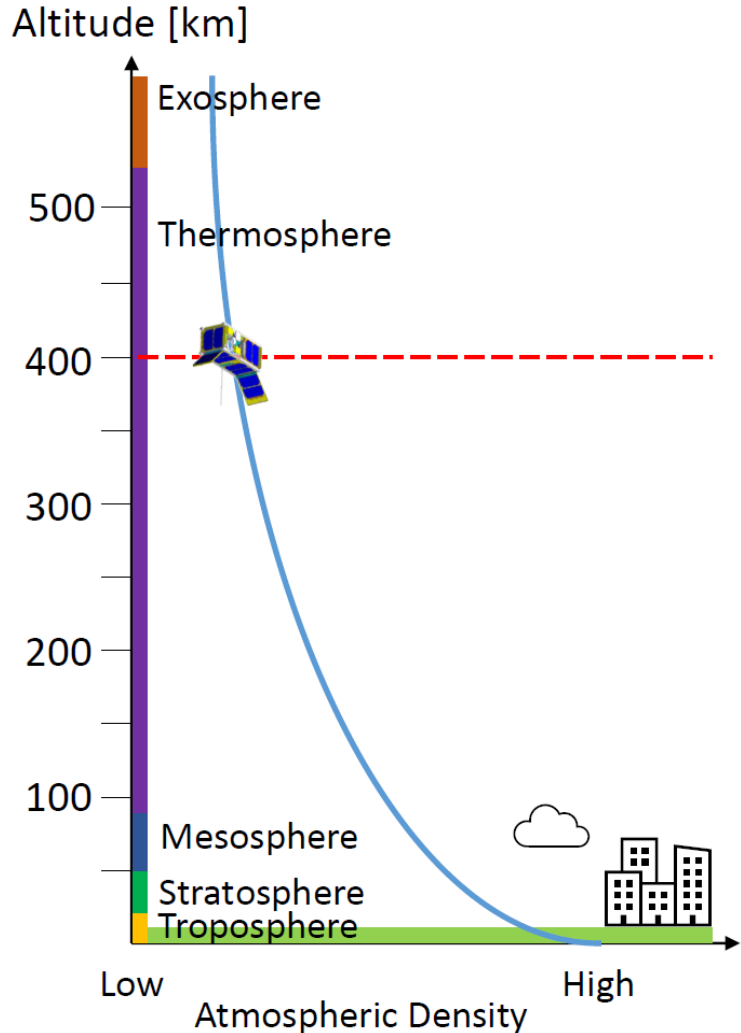


Hot Case



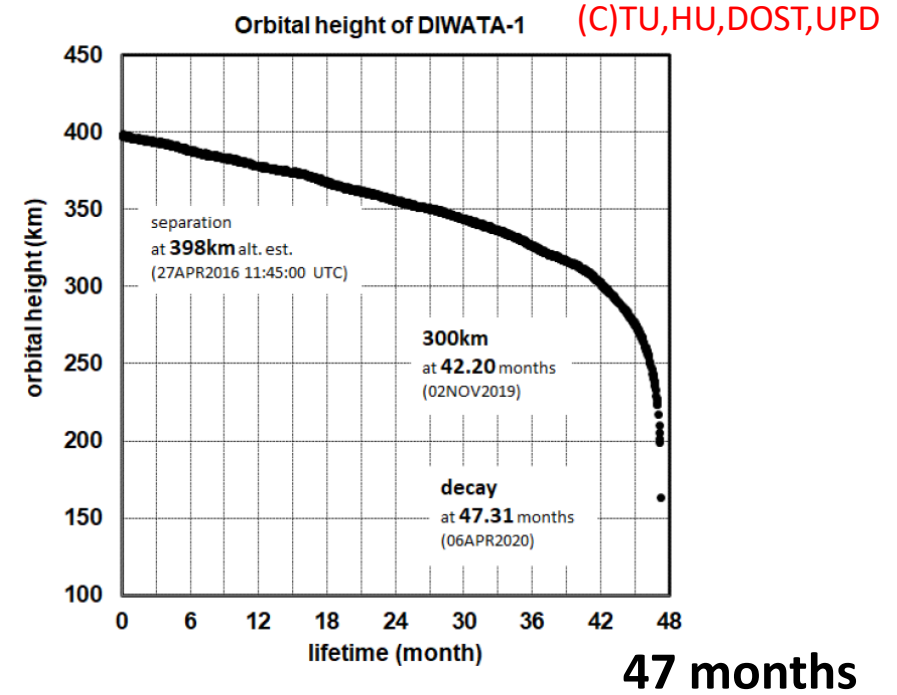
# 2. Satellite Orbit and Mission Lifetime

## Atmospheric Drag



2U CubeSat RAIKO

**2.7 kg**



50-kg microsatellite DIWATA-1

**52.4 kg**

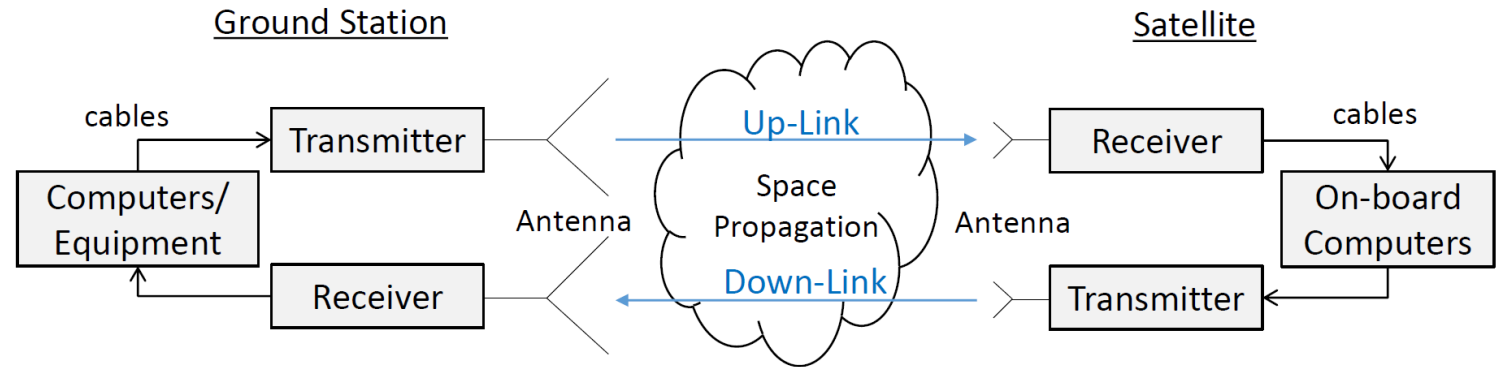


# 3. Communication System

# 3. Communication System

## Introduction to Communication System

- Communication system is required for:
  - upload commands
  - download house-keeping data and mission data
- Typical frequencies:
  - VHF (around 144 MHz, amateur radio)
  - UHF (around 435 MHz, amateur radio)
  - S-band (around 2 GHz)
  - X-band (around 8 GHz)

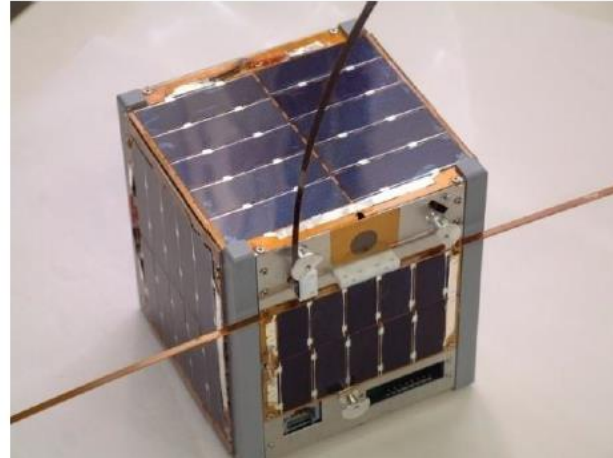
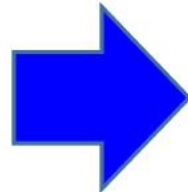
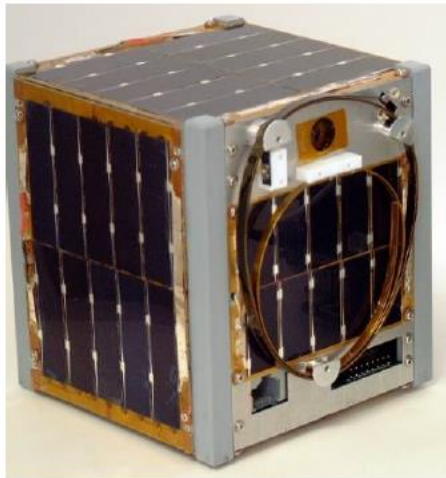


Typical CubeSat RF Transmitter and Receiver © Addnics corp.

# 3. Communication System

## Deployable Antenna

- **Lower frequency** bands require **longer antennas**.
- Typical frequencies: **UHF** (around 144MHz) and **VHF** (around 435MHz)
- Merit: **reasonable prices** for the setup of amateur radio **ground station**
- Data rate can be slow (**1.2kbps, 9.6kbps, 38.4kbps**, etc.)
  - limited assigned band width
- **Folded antennas must be automatically deployed** for communications



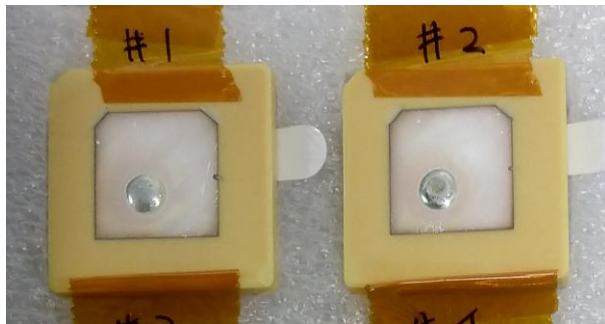
XI-IV © University of Tokyo

# 3. Communication System

## Patch Antenna

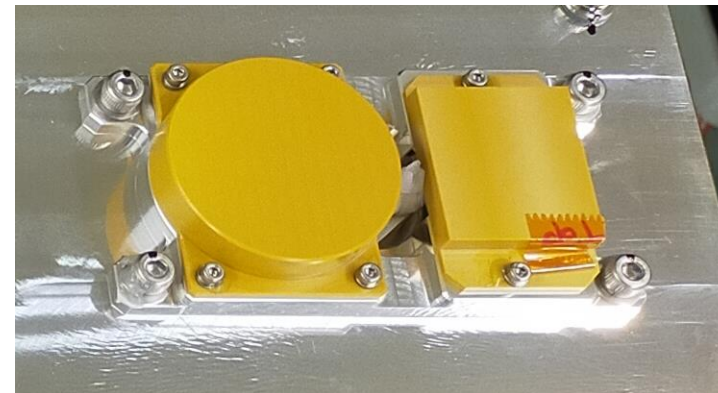
- **S-band (2GHz)** and **X-band (8GHz)** will be used for **high-speed data** communications
  - example, **2Mbps** (0.5W out) by S-band, **20Mbps** (1.0W out) and more by X-band
  - **wide assigned bandwidth** especially for X-band
- **Demerit:** ground station **cost** (large parabola antenna system)
- **No deployment mechanism** required => low risk of communication failure

patch antennas



(C) Tohoku Univ.

assembly



(C) Tohoku Univ.

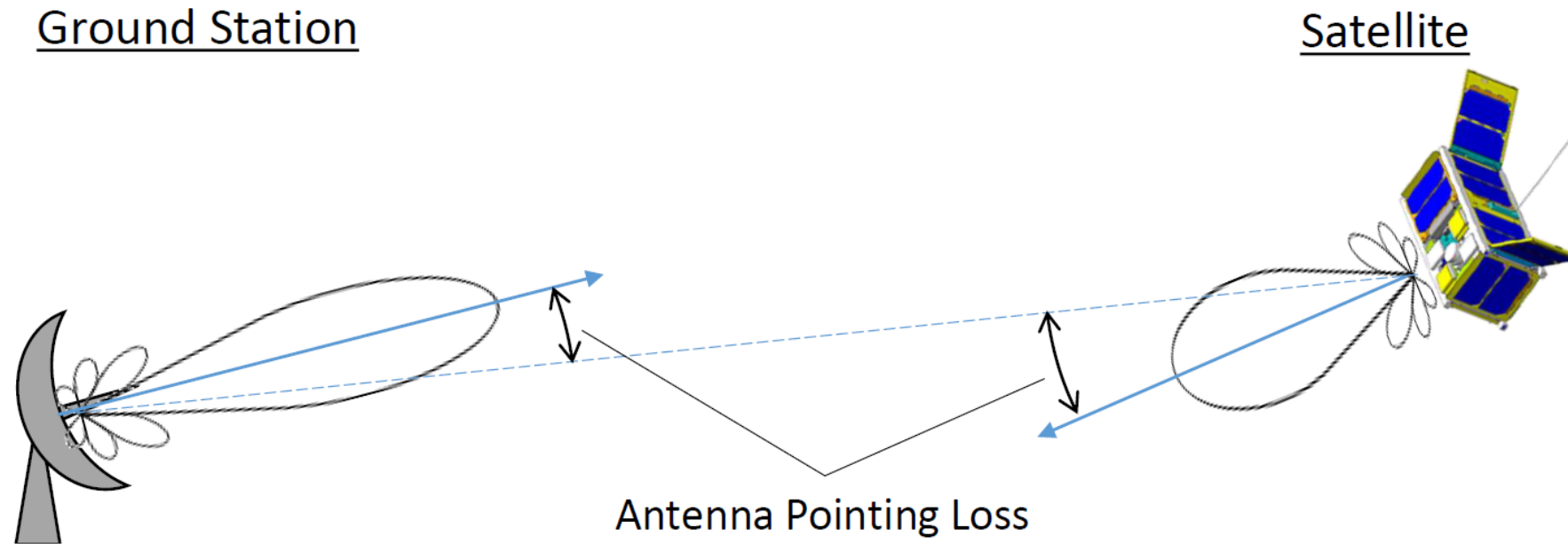
patch antennas  
with covers  
(for GPS and S-band uplink)



# 3. Communication System

## High Gain Antenna

- **High gain antennas** require **pointing control** to satellite or ground station
- **Narrow beam** width can achieve **higher gain**
- **Power resource is required** for both **transmission amp** and **attitude control** components

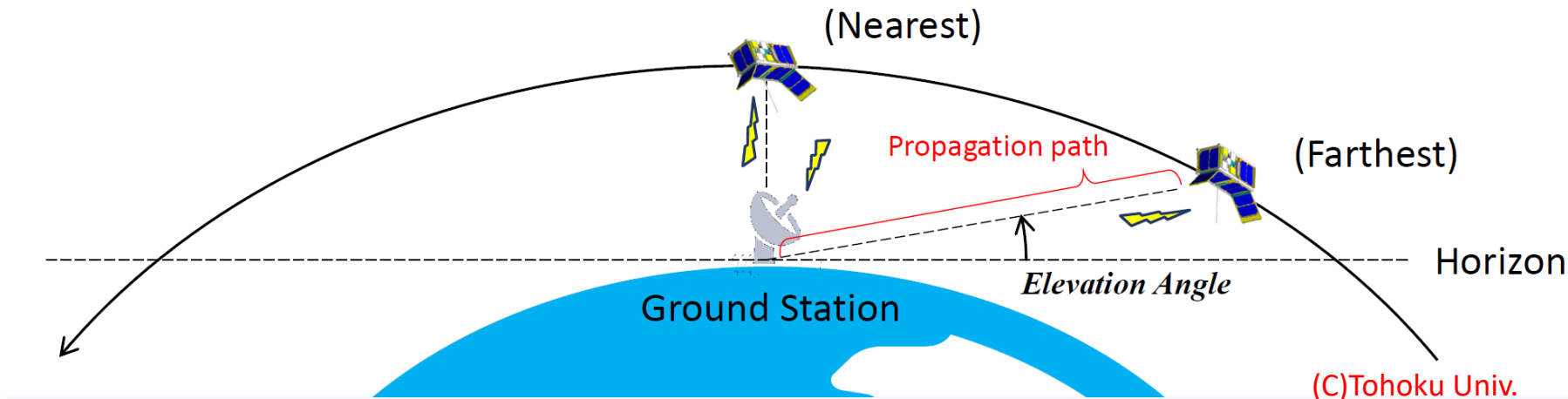


(C)Tohoku Univ.

# 3. Communication System

## Link Budget Design

- **Specs** of communication system can be designed by **link budget** analysis. Acceptable **data rate** (10kbps, 100kbps, 1Mbps, etc.) can be **calculated** by the **balance of hardware specs**.
1. Hardware specs of **both satellite and ground station**: **antenna** (size and gain), **transmitter** (output power), **receiver** (minimum input signal levels)
  2. Data **modulation**: modulation type (FSK, BPSK, QPSK, etc.)
  3. Orbit: **distance at nearest and farthest** (satellites around horizon)





# 4. Ground Station

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# 4. Ground Station

## Types of Ground Stations

- **Ground station antenna** must be **controlled** to point toward the satellite during observation chance
- **Future satellite position** can be **calculated**
- **Satellite orbits** at reference times are **available in the Two Line Element (TLE) format**, which are distributed by [celestrak.com](http://celestrak.com) etc.



Yagi-Antenna for VHF-band

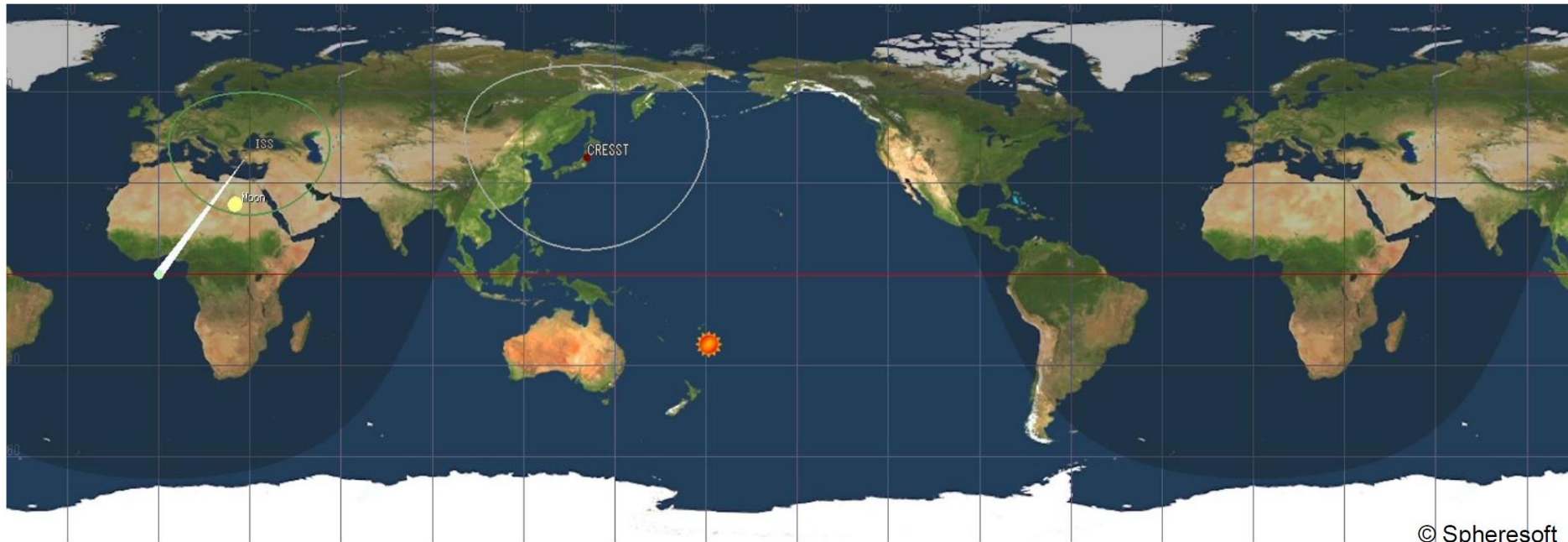


Dish-Antenna for S-Band

# 4. Ground Station

## Geographical Position for the Ground Station

- The **latitude** of CubeSats deployed from the ISS is between about **+/-51.6 degrees**. Their ground stations need to be located in that region.
- **Multiple ground stations for telemetry** downlink can be prepared around the world to **increase** the amount of **mission data** (accepted countries are defined by ITU applications except for amateur radio satellites)



# 4. Ground Station

## Items for Ground Station

1. Antenna with controllable motors
2. Transmitter and receiver with functions of suitable modulation/demodulation and coding/decoding
3. Operation software



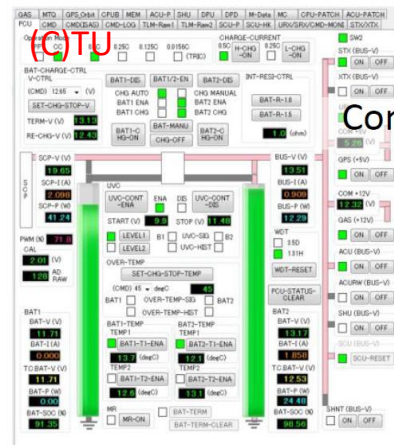
Operation Room



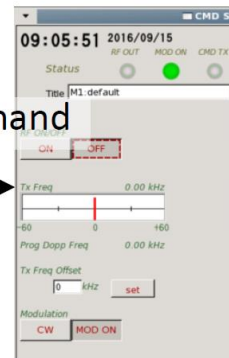
Up-link Signal

Down-link Signal

Antenna Control

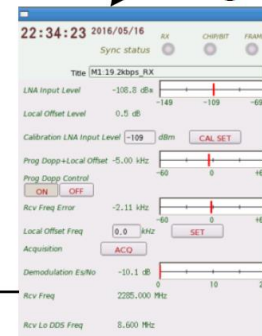


Satellite Control Software



Command

Telemetry



Dish-Antenna for S-Band



Virtual Tour 1:  
operation rooms

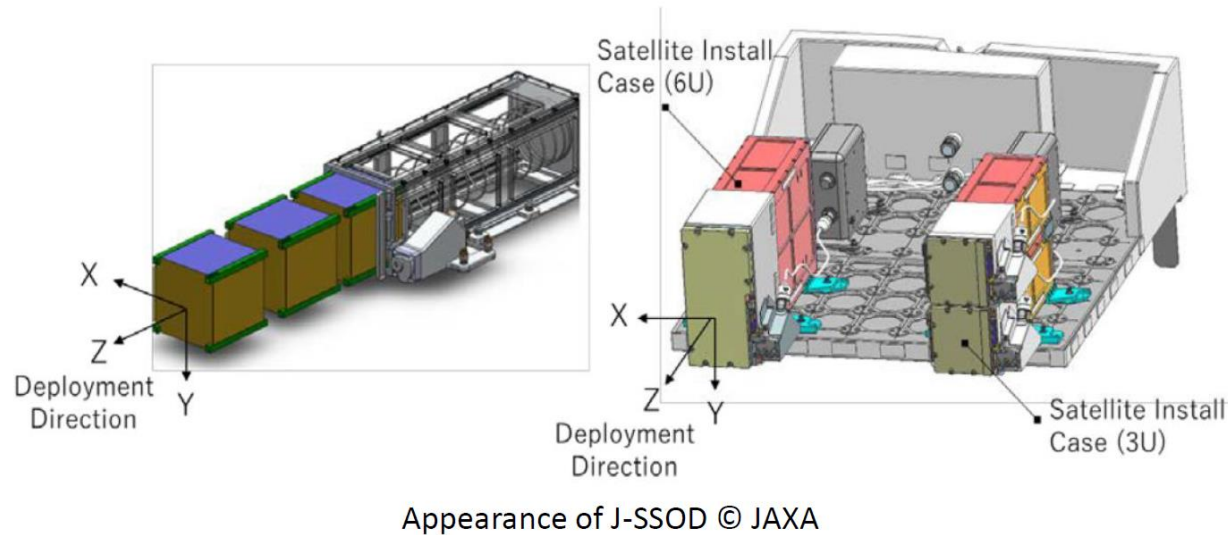


# 5. Launch and First Contact

# 5. Launch and First Contact

## Satellite Delivery

- Satellite is **delivered** to JAXA **several months before the launch**.
- CubeSats are **assembled into the J-SSOD**, deployment container
- After the ceremony, J-SSOD including CubeSats are **shipped to launch site** for further integration to the cargo spacecraft



Reference: JEM Payload Accommodation Handbook – Vol. 8 – (Japanese)  
<https://iss.jaxa.jp/kibouser/library/item/jx-esp-8d.pdf>

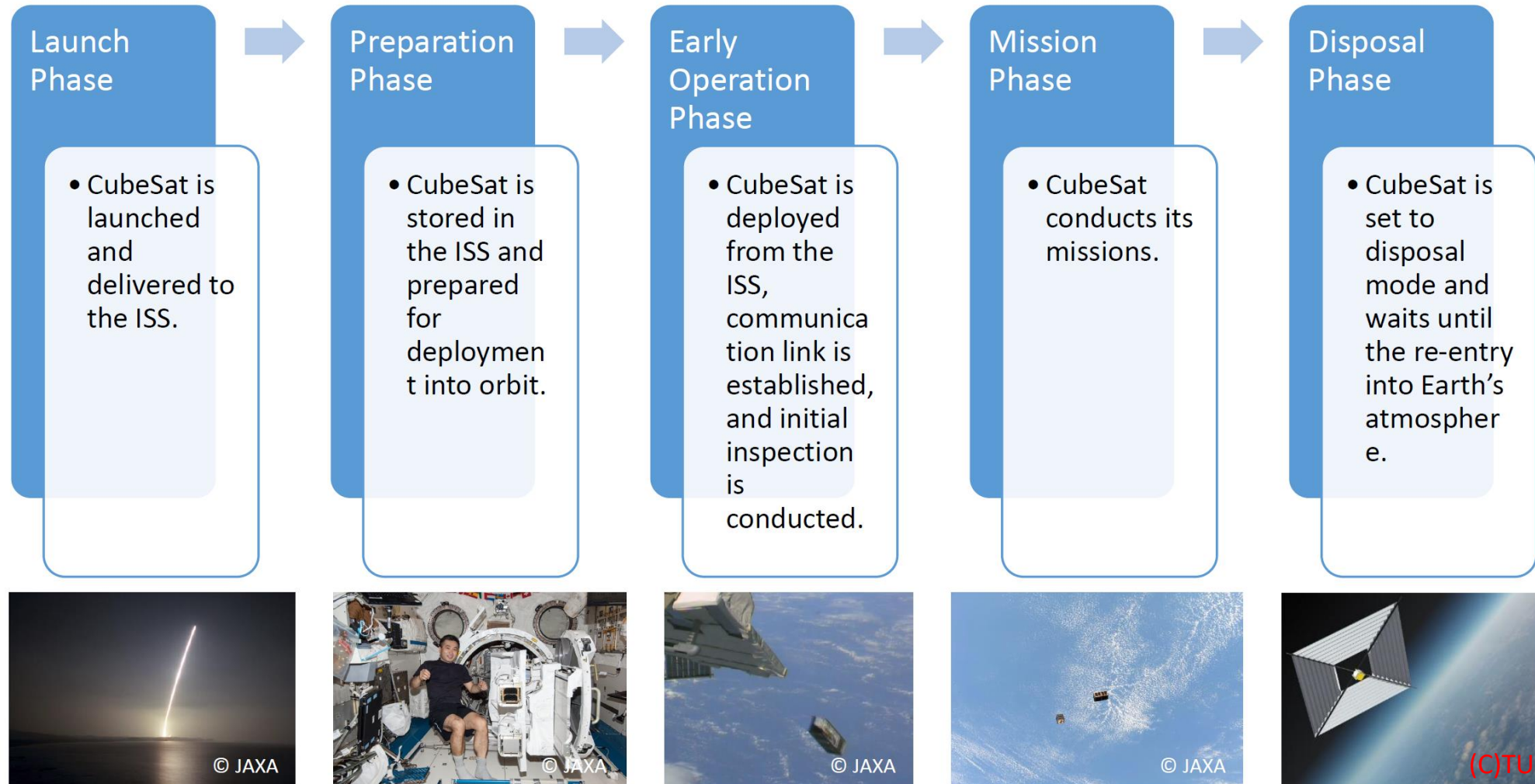


Satellite Delivery to JAXA



# 5. Launch and First Contact

## Operational Phase of CubeSat deployed from ISS



# 5. Launch and First Contact

## Launch Phase

1: Cargo spacecraft HTV is launched by launch vehicle H-IIB from the Tanegashima Space Center

- cargo spacecraft Cygnus is also available, this is launched from the US

2. HTV approaches and docks to the ISS after several days

3. J-SSOD containing CubeSats are handled inside the ISS

[!] CubeSats experience **mechanical vibration** during the launch

[!] **Power supply** for CubeSats **must be turned off** at all times until deployment to space



Launch and Delivery to the ISS © JAXA

# 5. Launch and First Contact

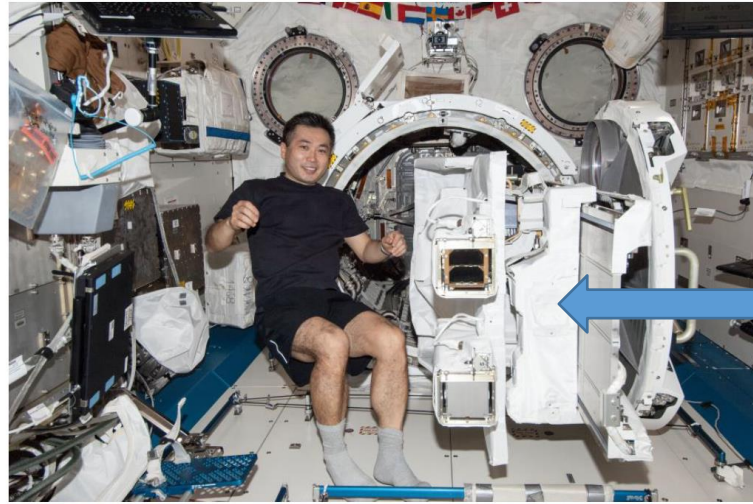
## Preparation for Satellite Deployment

4: CubeSats are prepared for deployment by **astronauts**

5. J-SSOD and deployment palette are **transferred to outside**

6. They are attached to the **tip of robotic arm of Kibo**

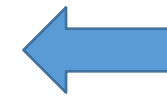
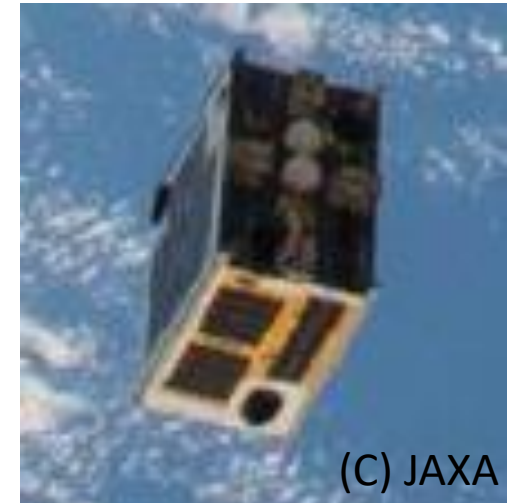
7. Astronaut **triggers the switch** for the deployment



Deployment preparation, and deployment from the ISS © JAXA

# 5. Launch and First Contact

## Satellite Deployment



**DIWATA-1 (2016, 52.4kg)**

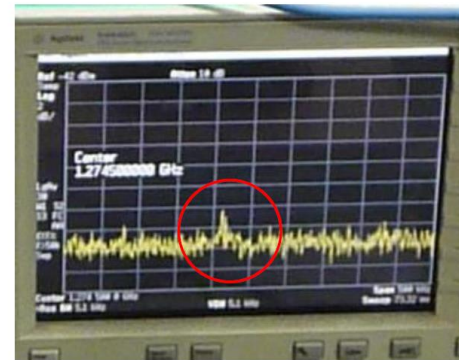
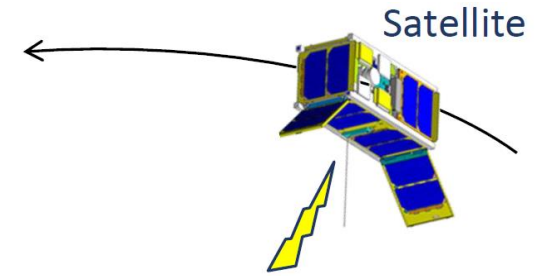
# 5. Launch and First Contact

## First Contacts

8. CubeSats **automatically start** the functions in space, including **RF transmission**

9. We observe **1st signals** from a satellite at the ground station, **most exciting moment**

10. **Satellite health** is checked including normal **power generation, battery charge, temperature** of components, etc.



# 5. Launch and First Contact

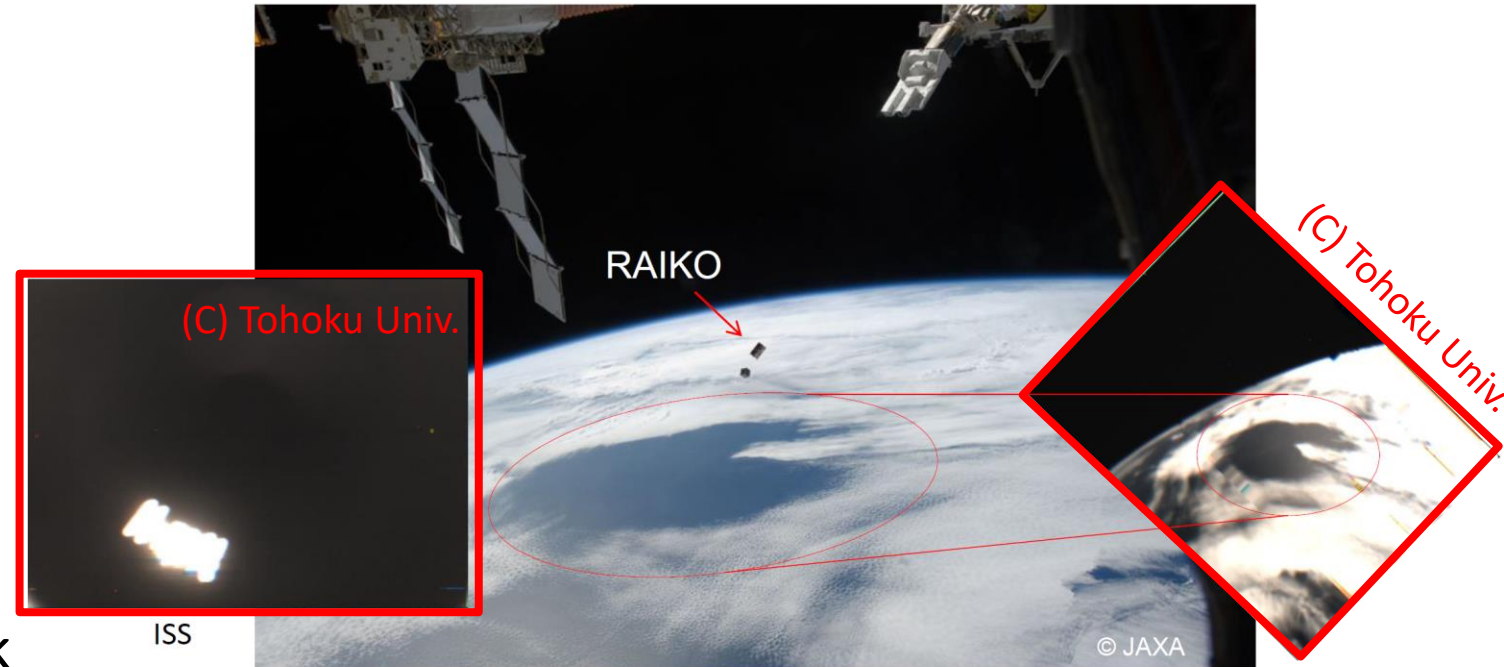
## First Light

11. We need to **confirm the successful of command uplink** as well as telemetry receiving.

- a lot of CubeSats had defects in command function

- [!] **be careful of the electrical noise environment inside of satellite**

12. We send commands of **camera trigger** and **data download**, and check the **1st light images**



Images obtained by CubeSat RAIKO just after the deployment from the ISS

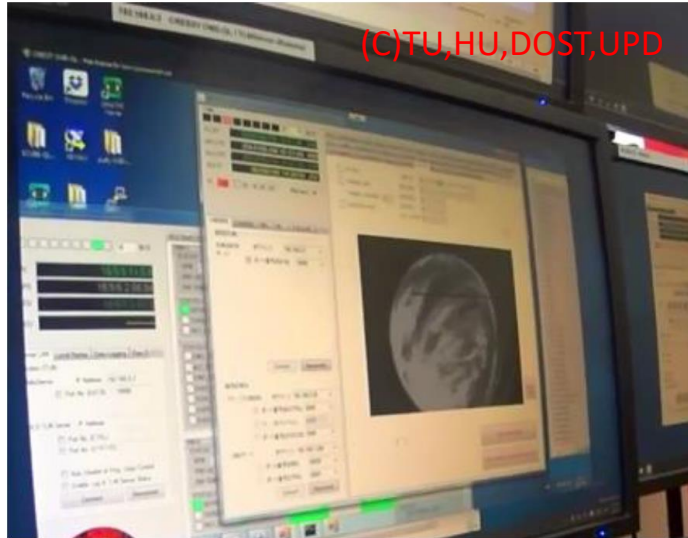
### 1st light images by RAIKO



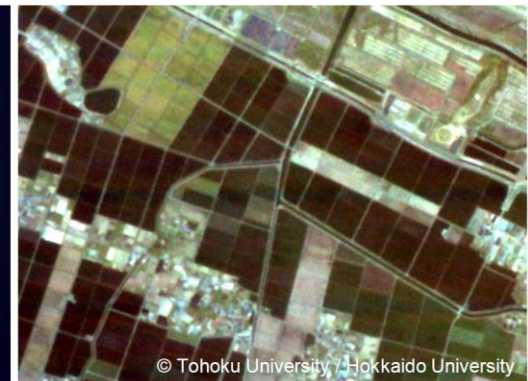
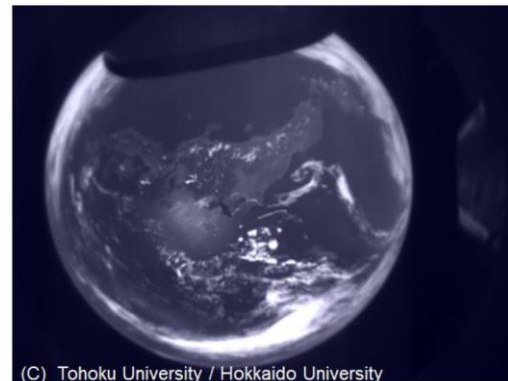
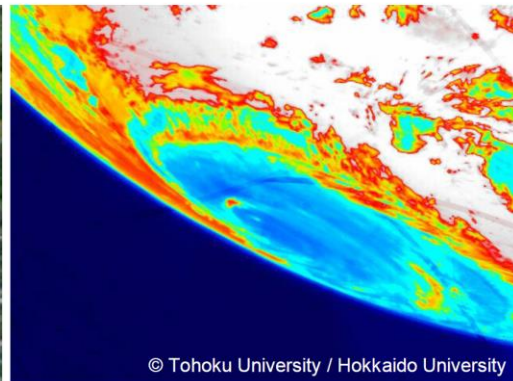
# 6. Mission Operations

# 6. Mission Operations

## Upload Commands and Download Status or Image Data



First-light obtained by the mission camera and downlinked to the ground station.

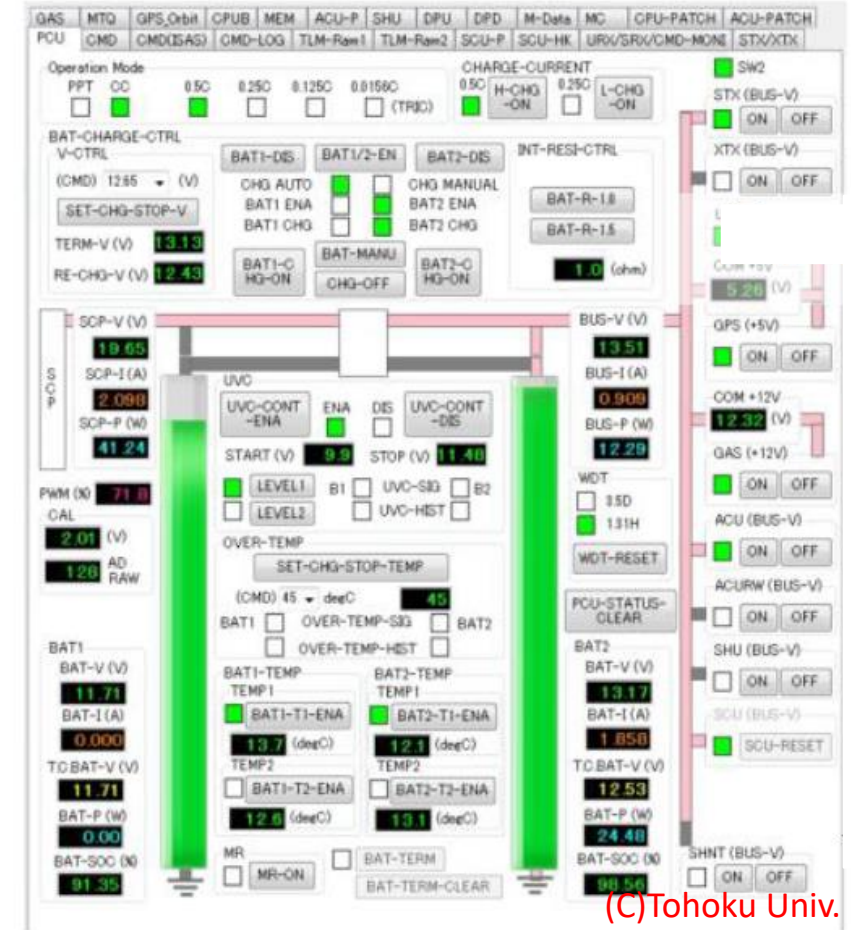




# 6. Mission Operations

## Realtime Monitor and Command

- Original software for **status decoding** and **quick commands** will be prepared.
  - solar **power generation** (SCP-V, I, P)
  - **power consumption** by bus components (BUS-V, I, P)
  - **battery charge/discharge** (BAT-V, I, P) & **temperature** (BAT-T)
  - **on/off state** of each bus component & on/off **quick commands**
  - **red alert lamps**
  - For quick treatment in **emergency cases**, **buttons for real-time quick command** will be prepared
  - **Command counter** (incremented by single command reception) will be **convenient**.
- => command link **cannot be stable** any time



Satellite Control Software

# 6. Mission Operations

## Stored Command

- **Stored command** function is **important** when we want to execute task in **invisible time**
- Uploaded commands are **not executed instantly** but just **stored in the on-board memory**
- Each command line is including the **specific date** to execute.
- **Combination of specific date and waiting time** will be **convenient** for **reusability of the procedure**

### example of stored command definition

```
0x01 01 #CAM-ON #WAIT=5 #DATE=2021/11/18 09:00:00 UTC
0x02 02 35 0130 #ATT-CONTROL-TO-TARGET(N35,E130) #WAIT=180
0x01 03 #CAM-TAKE-A-PHOTO #WAIT=5
0x01 04 #CAM-OFF #WAIT_A=5
```

#SC\_DATE ... specific date to execute the command

#SC\_WAIT\_A ... waiting time (sec) after the command execution

Text  
File  
-----  
-----  
-----



```
AB CD EF 01 01 ..
AB CD EF 02 02 ..
AB CD EF 03 00 ..
AB CD EF 04 00 ..
```



converted to **HEX binaries**  
(by Sat. Control Software)

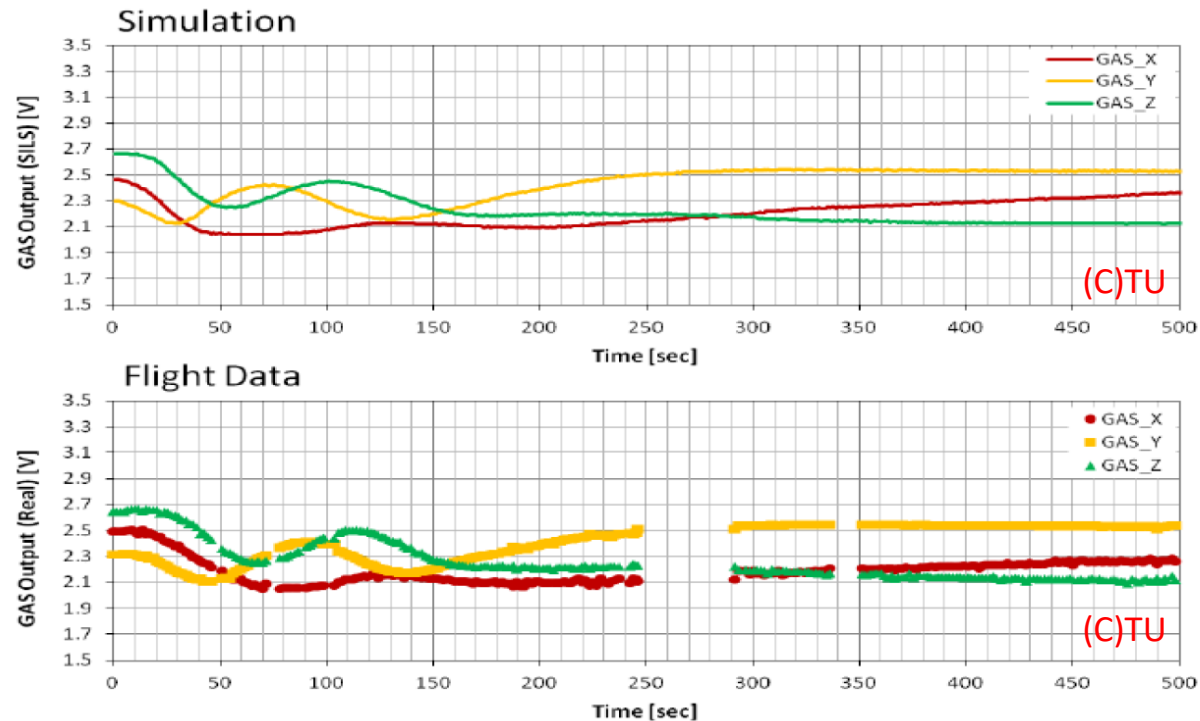


upload to satellite  
(C)TU,HU

# 6. Mission Operations

## Sensor Calibration

- According to the **simulation results** and **actual measurements**, software parameters set in on-board computers will be **adjusted**
- We often **mistake** the definitions of **plus/minus sign**, this cannot be avoided

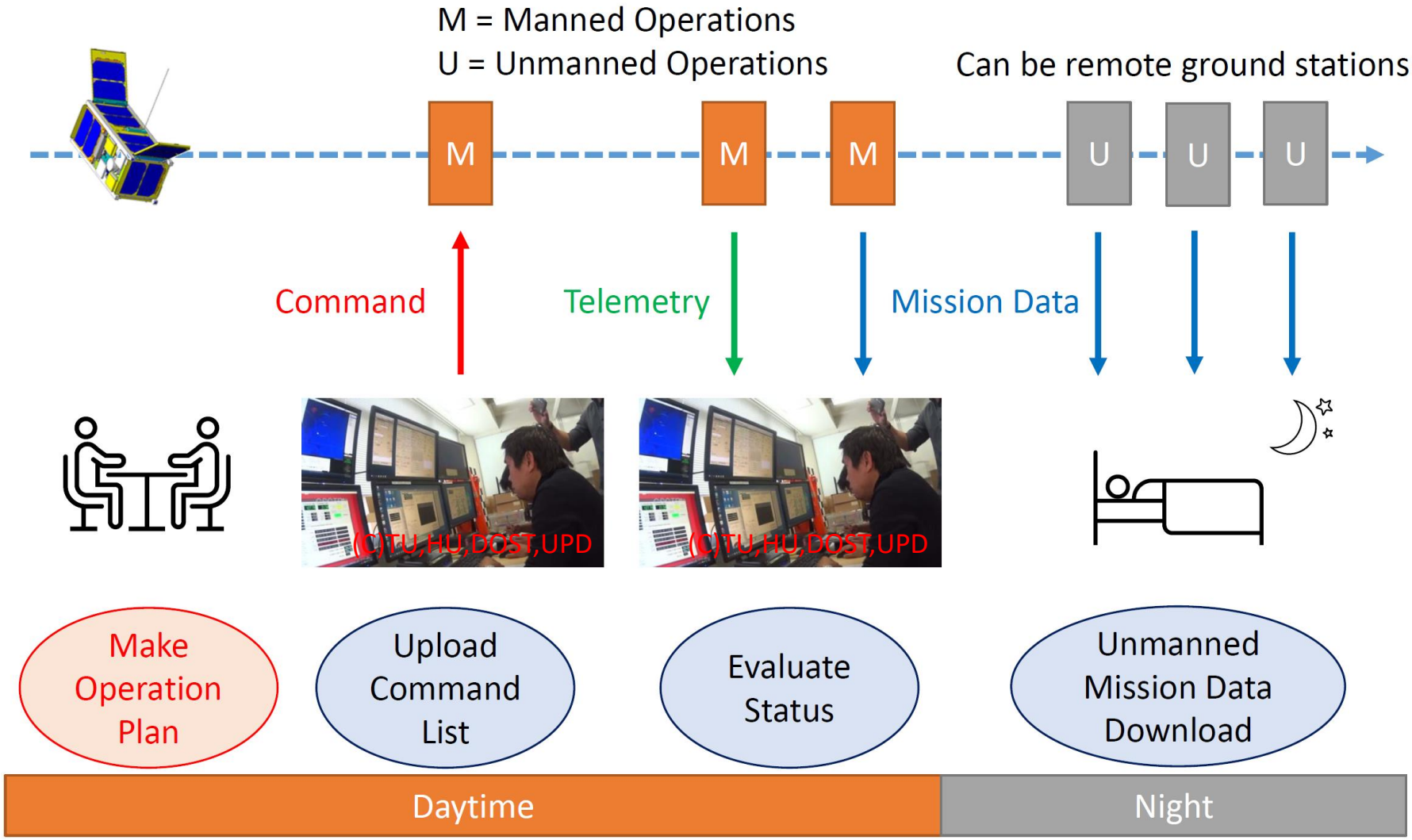


3-axis  
magnetic sensors

Analysis through comparison of simulation and flight data

# 6. Mission Operations

## Operation Routine



**Virtual Tour 2:  
Command Upload  
in Real Operation**



## 7. Conclusion

# 7. Conclusion

- **CubeSats** deployed from the **ISS** will follow **similar orbits** as the ISS.  
The orbit has **different illumination** conditions of the **Sun** throughout the year.
- **Mission duration** of a CubeSat depends on the mechanical characteristics, such as **mass and size**, and the **magnitude of solar activity**.
- **Link budget** between the CubeSat and the ground station shall be carefully **designed** for steady communication in both directions: Up link and Down link.  
**[!] more important: noise condition inside of satellite** must be **carefully surveyed** and **decreased** as much as possible. A lot of CubeSats ended in failure by a **command link malfunction**.
- Thorough mission planning, **ground evaluation**, **stepwise orbit verification**, and **efficient operation framework** are important.



**Thank you very much.**

[Disclaimer]

The views and opinions expressed in this presentation are those of the authors and do not necessarily reflect those of the United Nations.