KiboCUBE Academy

Lecture 17

Introduction to CubeSat Operation and Ground System

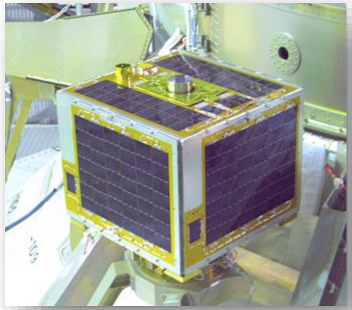
Hokkaido University

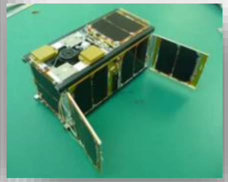
Division of Mechanical and Aerospace Engineering

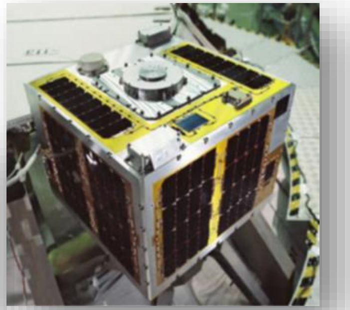
Associate Professor Dr. Yuji Sakamoto

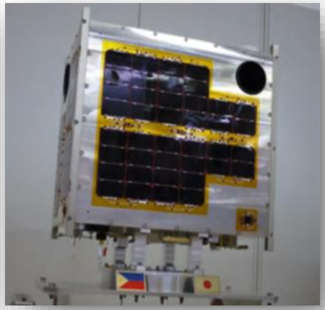
This lecture is NOT specifically about KiboCUBE and covers GENERAL engineering topics of space development and utilization for CubeSats.
The specific information and requirements for applying to KiboCUBE can be found at:
https://www.unoosa.org/oosa/en/ourwork/psa/hsti/kibocube.html

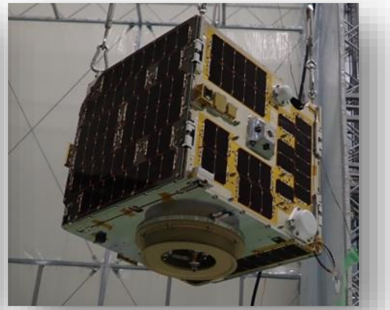
Lecturer Introduction











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

Research Topics:

Design, Assembly, and Evaluation of Micro and Nano Satellites
Satellite Operation and Ground Station Management

Contents

[!] Section 1 to 6, same as KiboCUBE LiveSession 2021 Satellite Operations.
Only Section 7 is new session in this lecture.

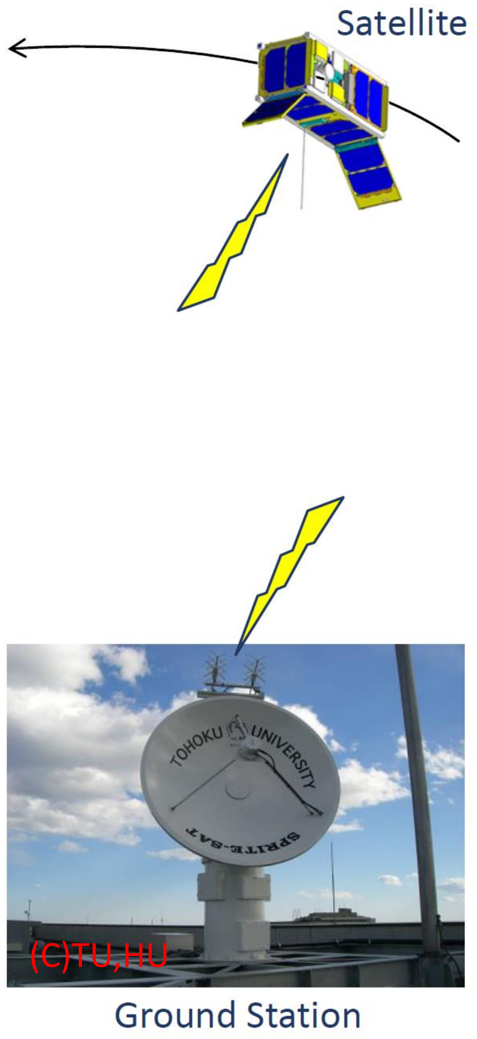
1. Introduction to Satellite Operations

1. Introduction to Satellite Operations

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.

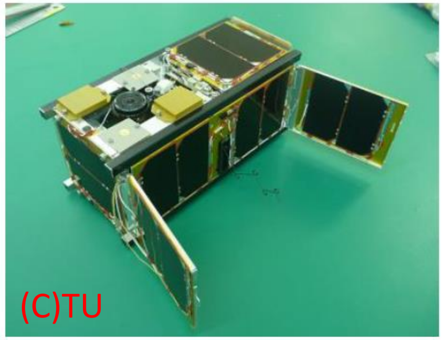


1. Introduction to Satellite Operations

- 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

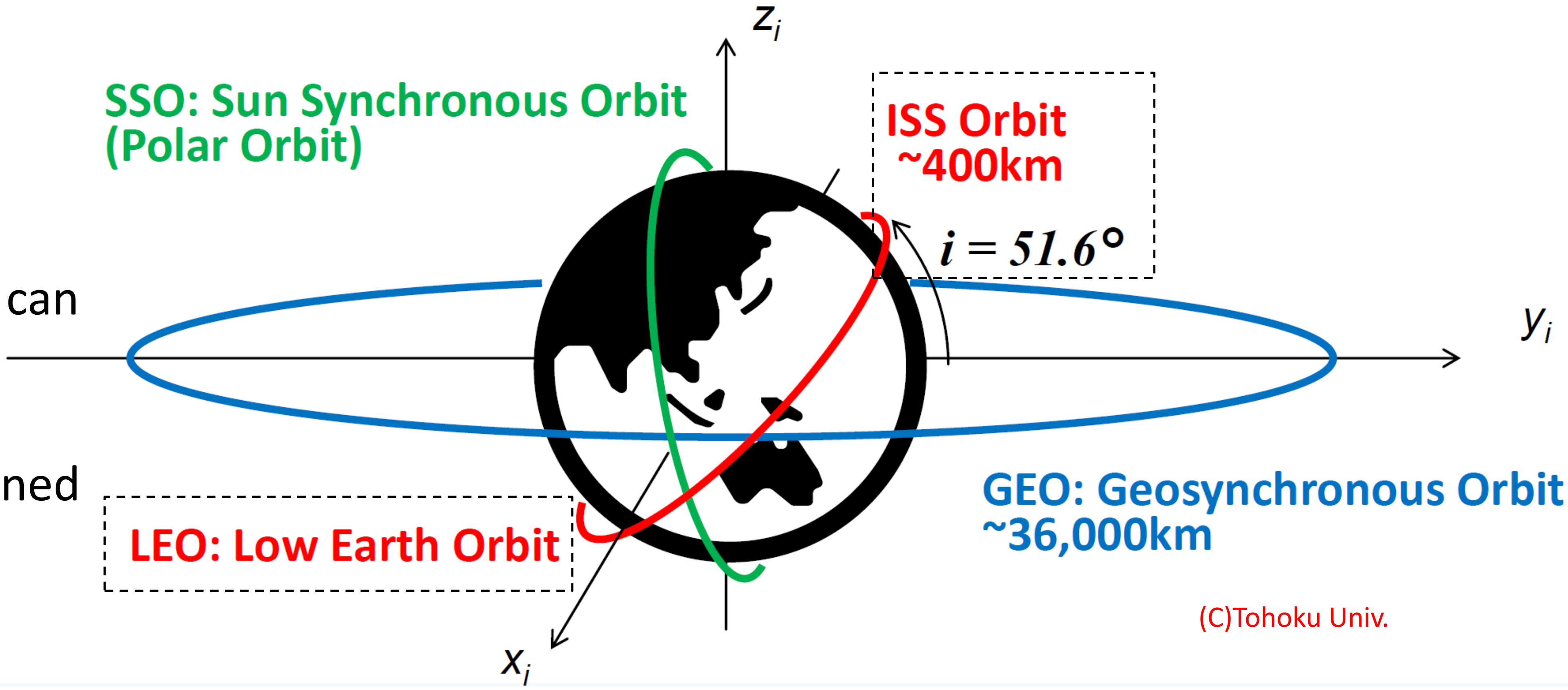
Satellite Operators

2. Satellite Orbit and Mission Lifetime

2. Satellite Orbit and Mission Lifetime

Type of Satellite Orbits

Low Earth Orbit has
1. **Many launch** opportunities
2. **Short distance** to Earth
=> communication **transmitting power** can be **decreased**
=> **high resolution images** can be obtained

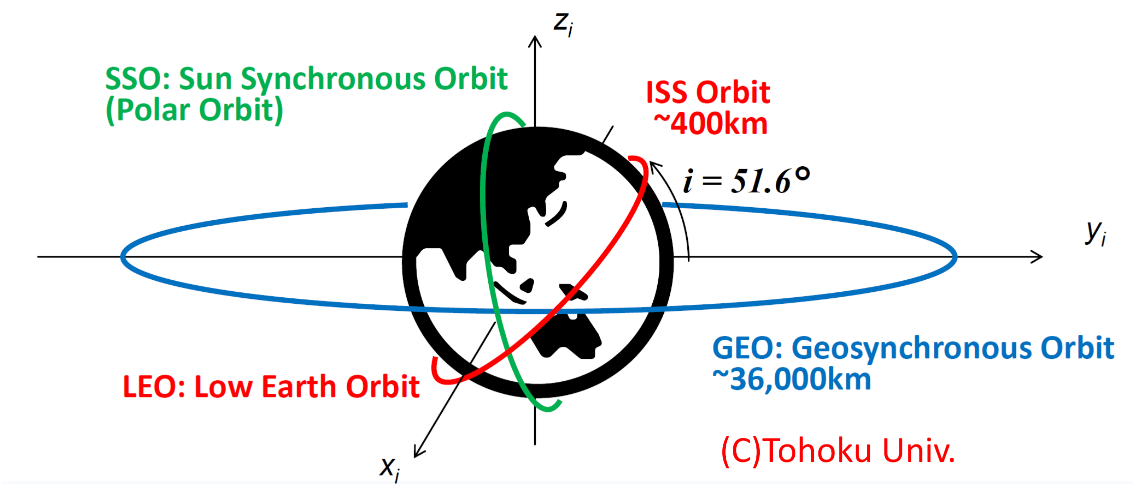


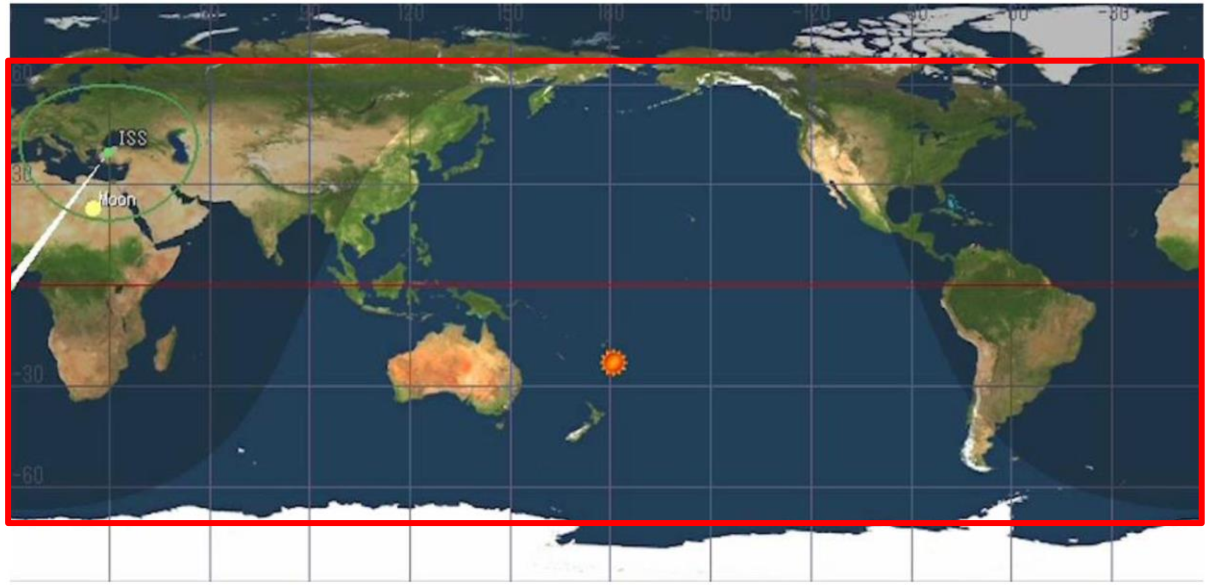
2. Satellite Orbit and Mission Lifetime

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



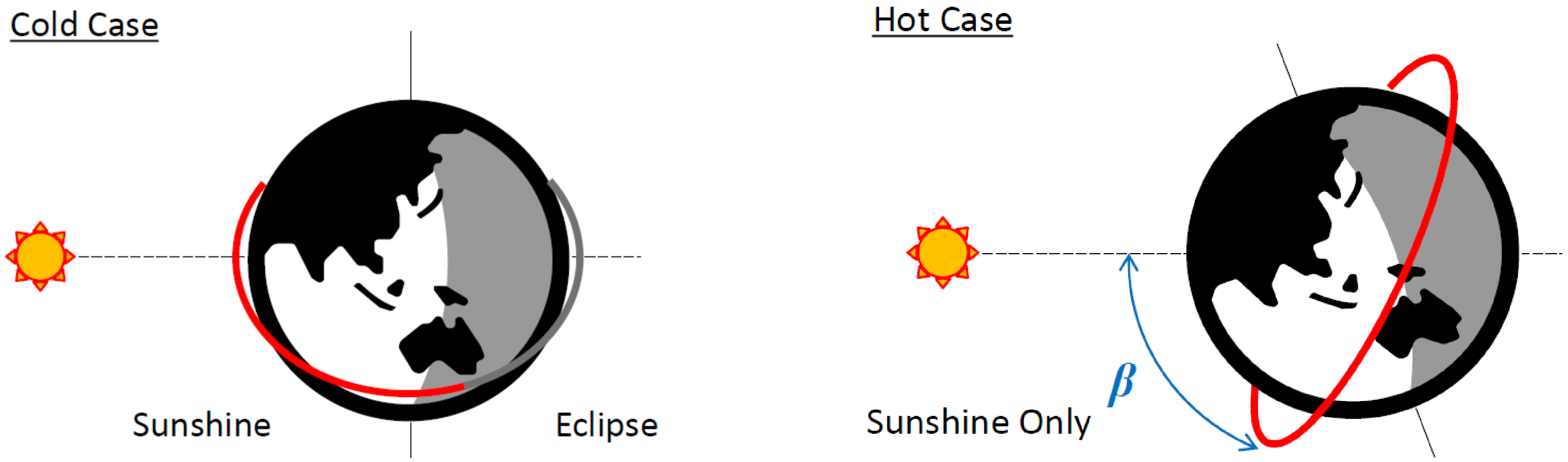


Spheresoft

2. Satellite Orbit and Mission Lifetime

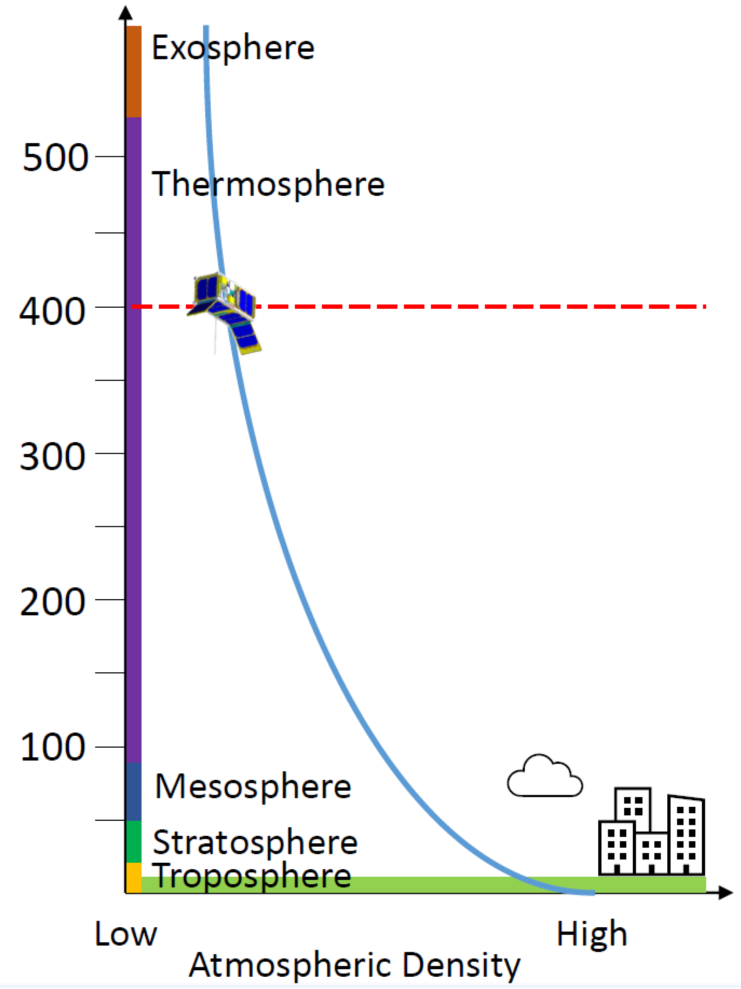
Influence of the Eclipse

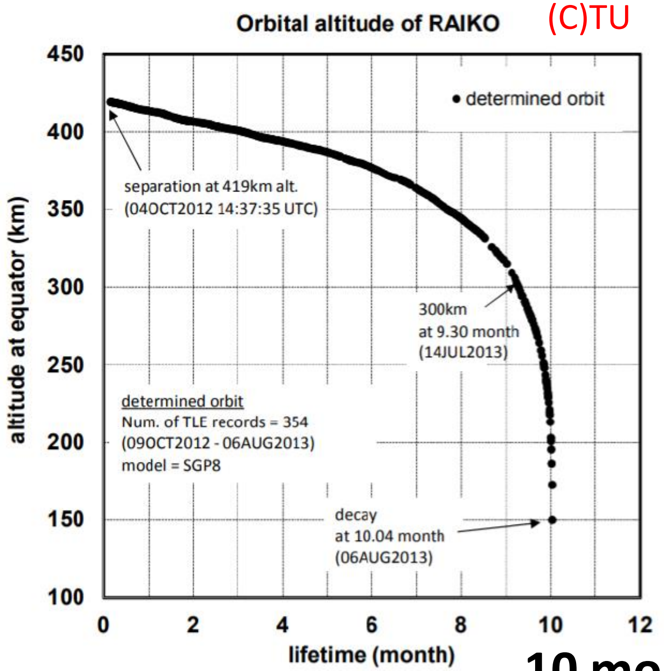
- For ISS released satellites, **all sunshine phase** continues for a few days **around summer and winter**
- **Solar angle to orbit** (= beta angle) can be **more than 70 degrees**.
- **0 deg in Cold** Case can be increased to **40 or 50 degrees in Hot** Case



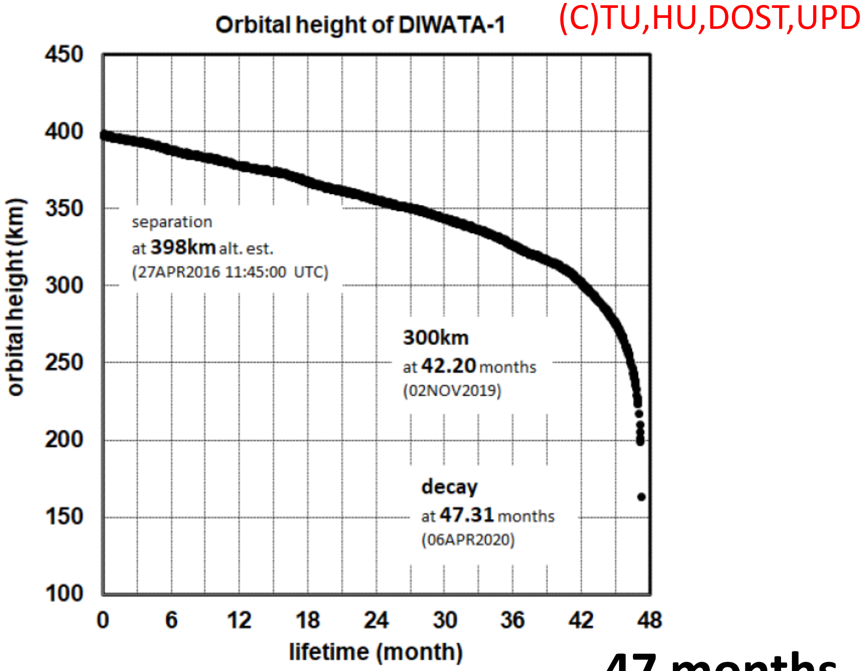
2. Satellite Orbit and Mission Lifetime

Atmospheric Drag

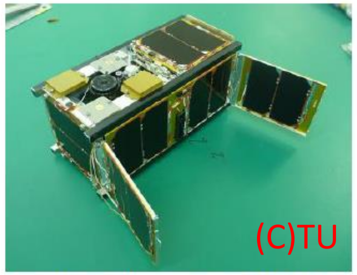




10 months



47 months



2U CubeSat RAIKO

2.7 kg

50-kg microsatellite DIWATA-1

52.4 kg

3. Communication System

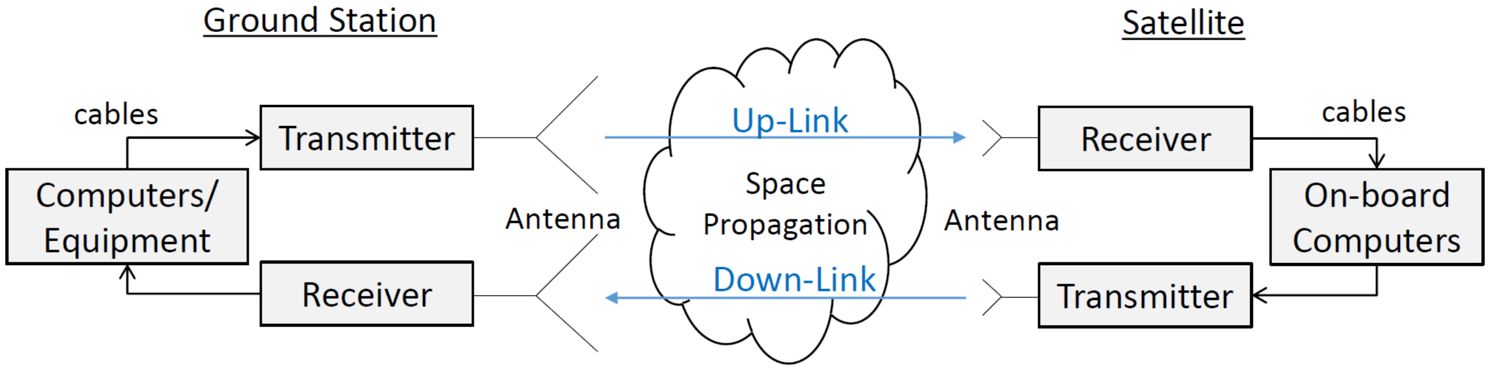
3. Communication System

Components for Satellite and Ground Station

- 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)

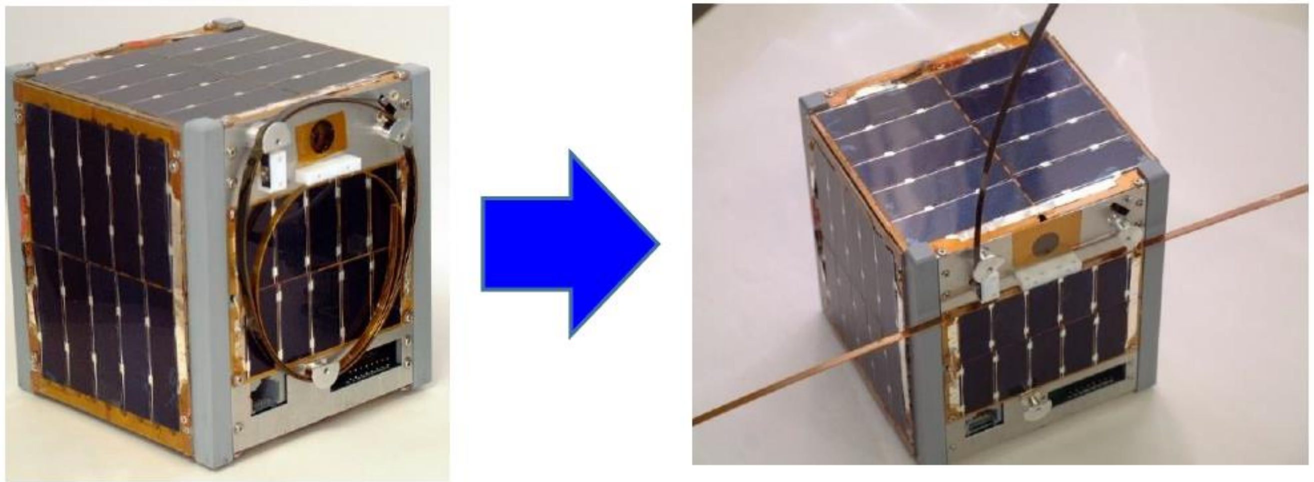
- S-band (around 2 GHz)

- X-band (around 8 GHz)

Typical CubeSat RF Transmitter and Receiver © Addnics corp.

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



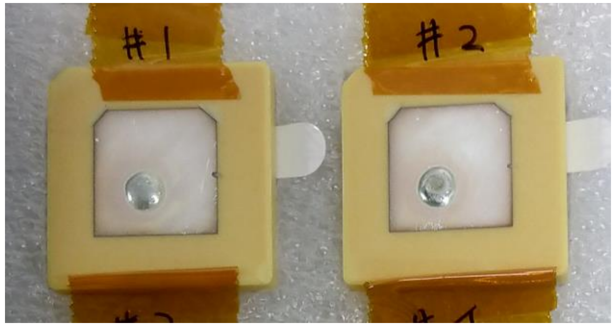
XI-IV © University of Tokyo

3. Communication System

Patch Antenna

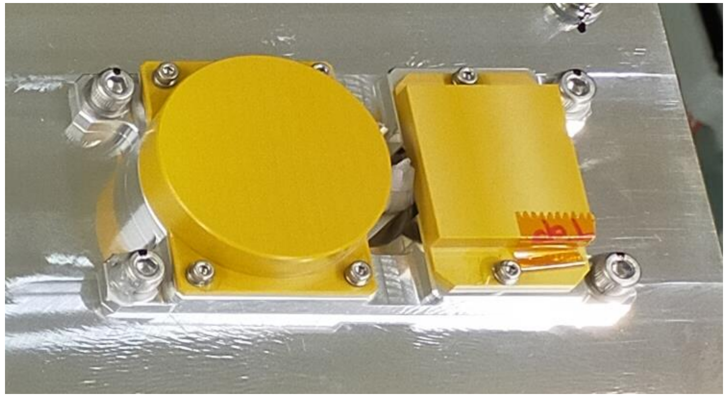
- **S-band (2GHz)** and **X-band (8GHz)** will be used for **high-speed data** communications
  - example, **2Mbps** (0.5W out) by S-band, **20Mbps** (1.0W out) and more by X-band
  - **wide assigned bandwidth** especially for X-band
- **Demerit**: ground station **cost** (large parabola antenna system)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

patch antennas



(C) Tohoku Univ.

assembly



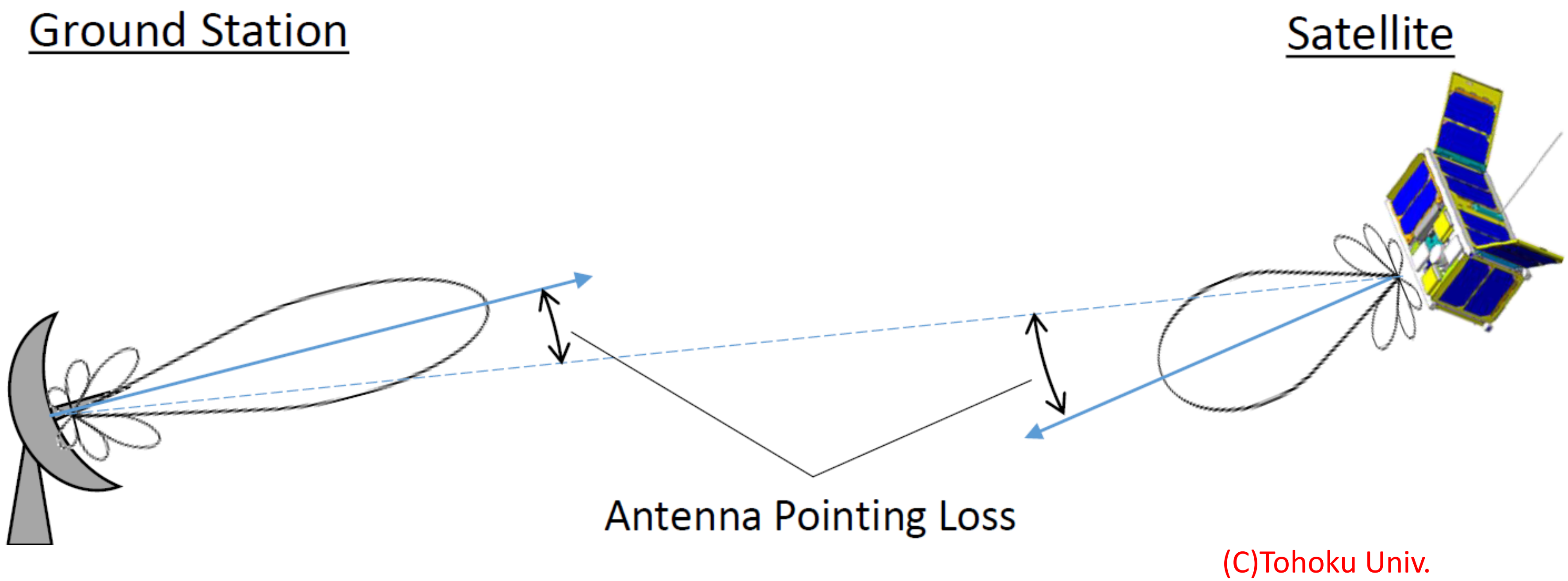
(C) Tohoku Univ.

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

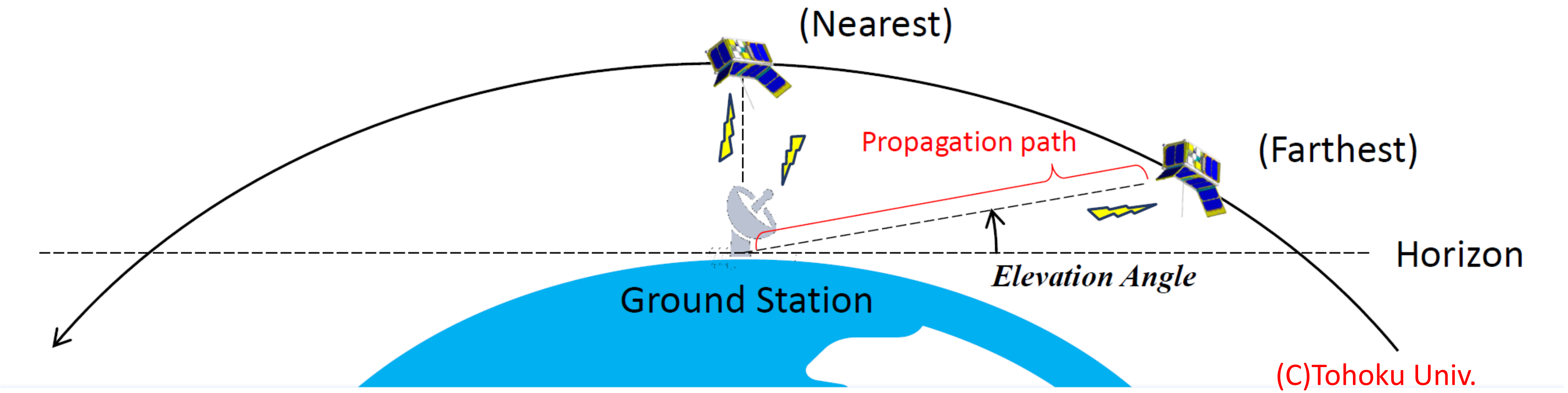


3. Communication System

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

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 etc.

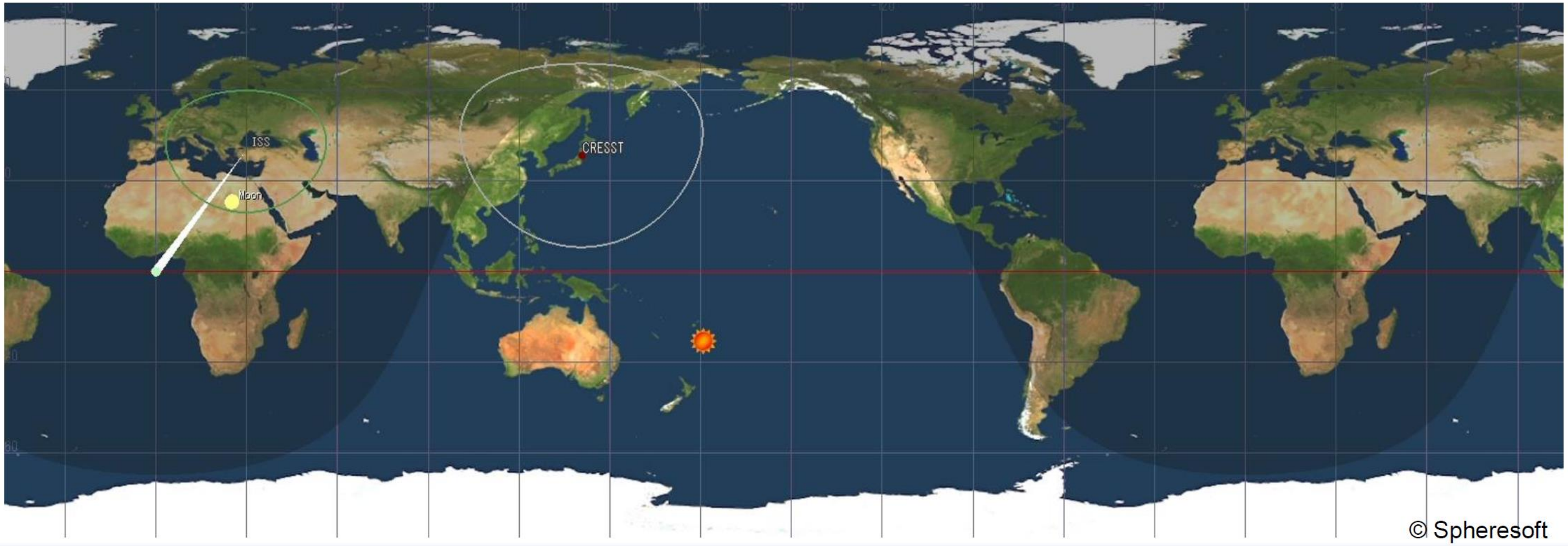
Yagi-Antenna for VHF-band

Dish-Antenna for S-Band

4. Ground Station

Geographical Positions

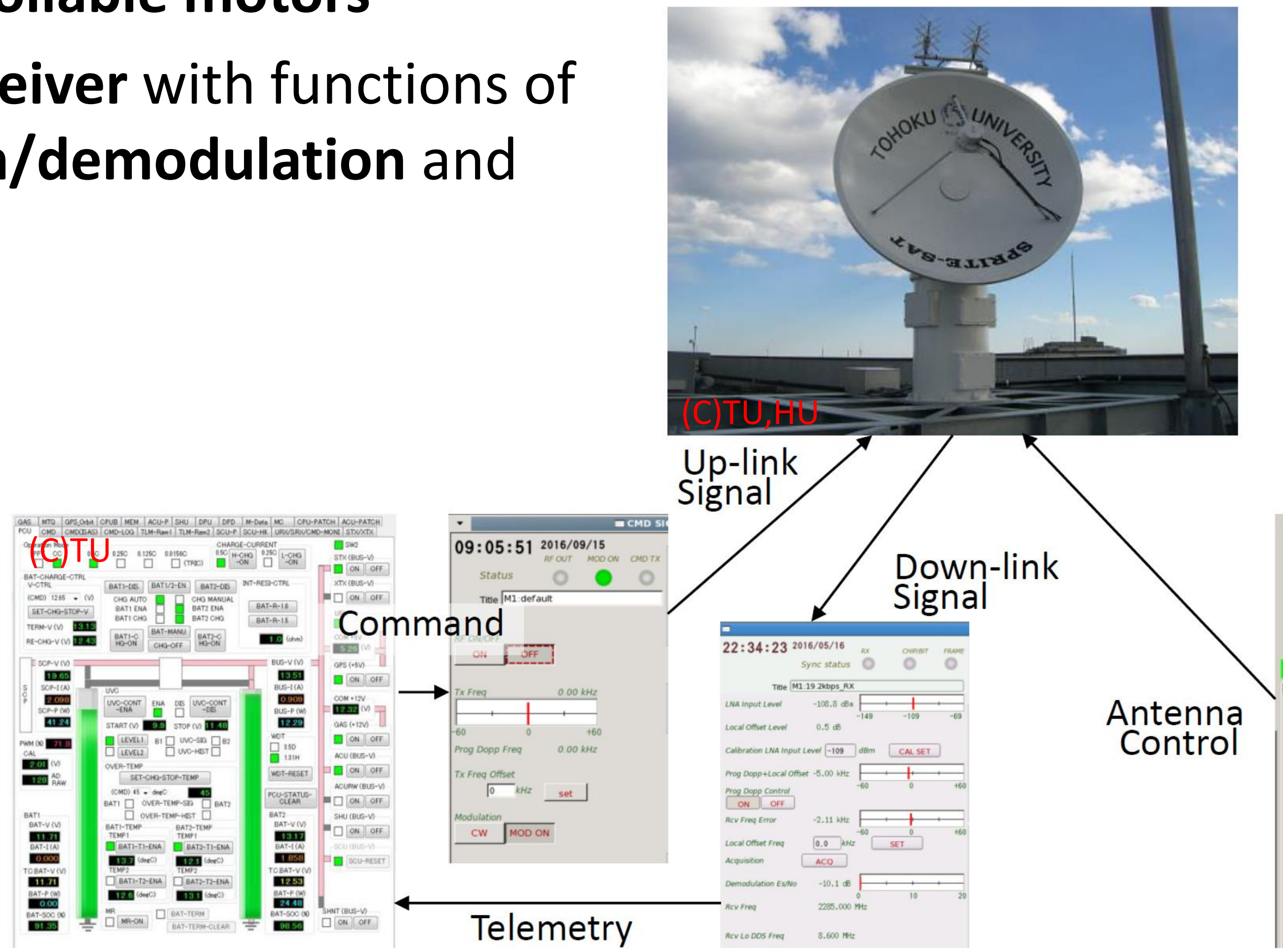
- The **latitude** of CubeSats deployed from the ISS is between about **+-51.6 degrees**. Their ground stations need to be located in that region.
- **Multiple ground stations** for **telemetry** downlink can be prepared around the world to **increase** the amount of **mission data** (accepted countries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



Components and Software

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

Operation Room



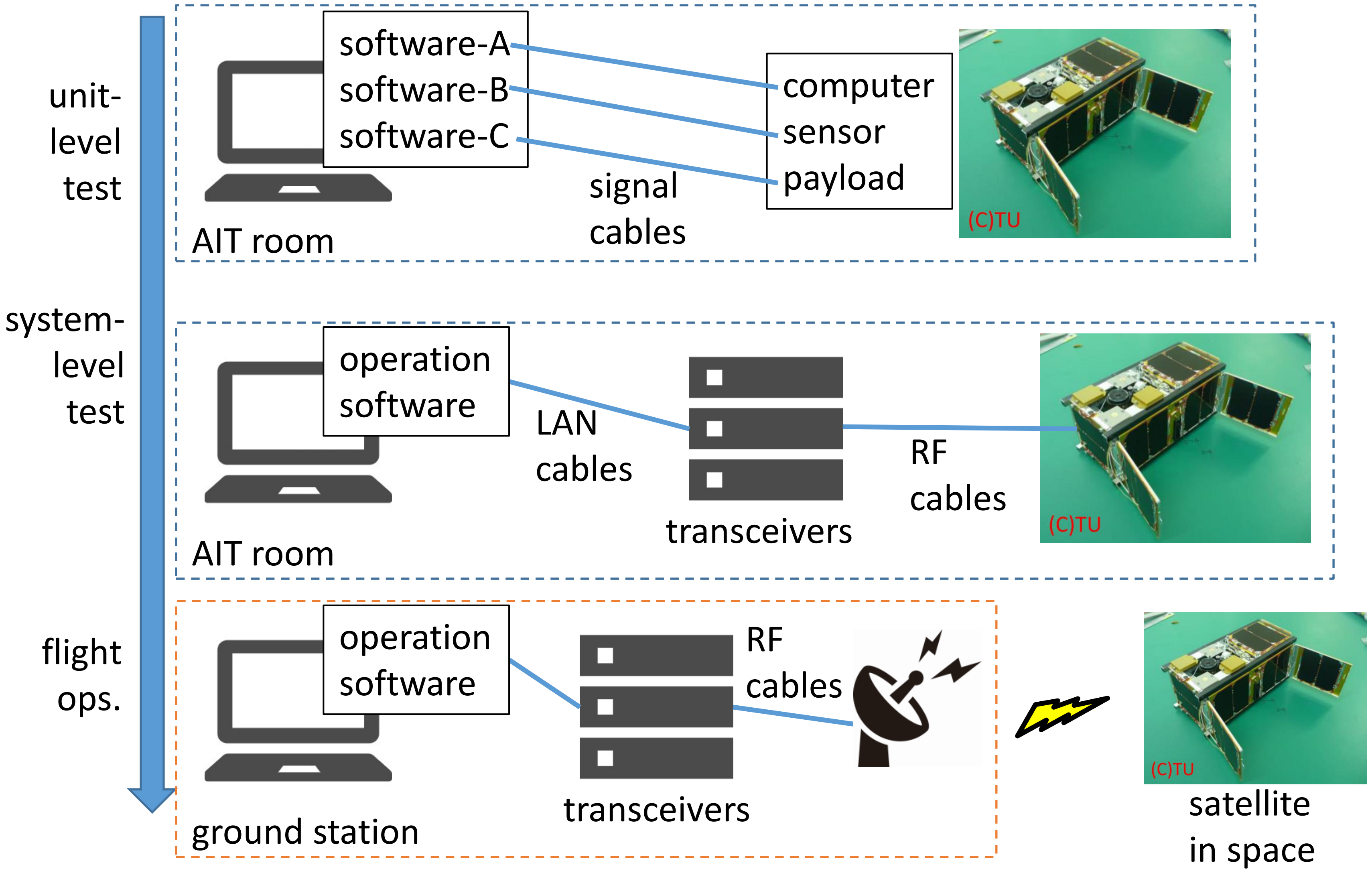
Satellite Control Software

Dish-Antenna for S-Band

4. Ground Station

Importance in Pre-Launch Testing

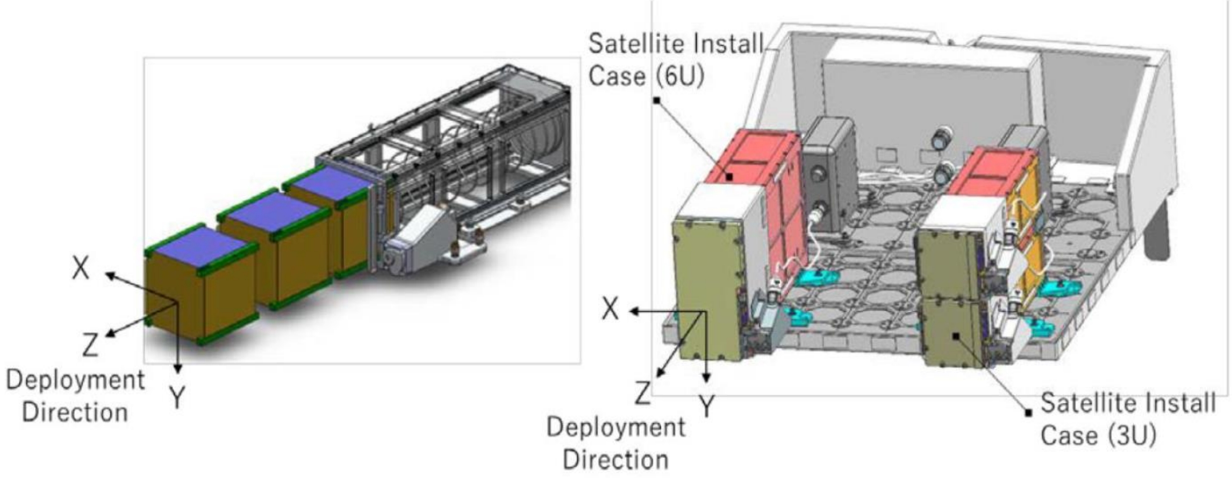
- Transceivers for ground station and operation software are necessary in system electrical test phase
- Demonstration of flight operation scenarios in system tests can improve the operation software and also the onboard satellite software (complete before satellite handover)



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



Appearance of J-SSOD © JAXA

Reference: JEM Payload Accommodation Handbook – Vol. 8 – (Japanese)
https://iss.jaxa.jp/kibouser/library/item/jx-espc_8d.pdf

Satellite Delivery to JAXA

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

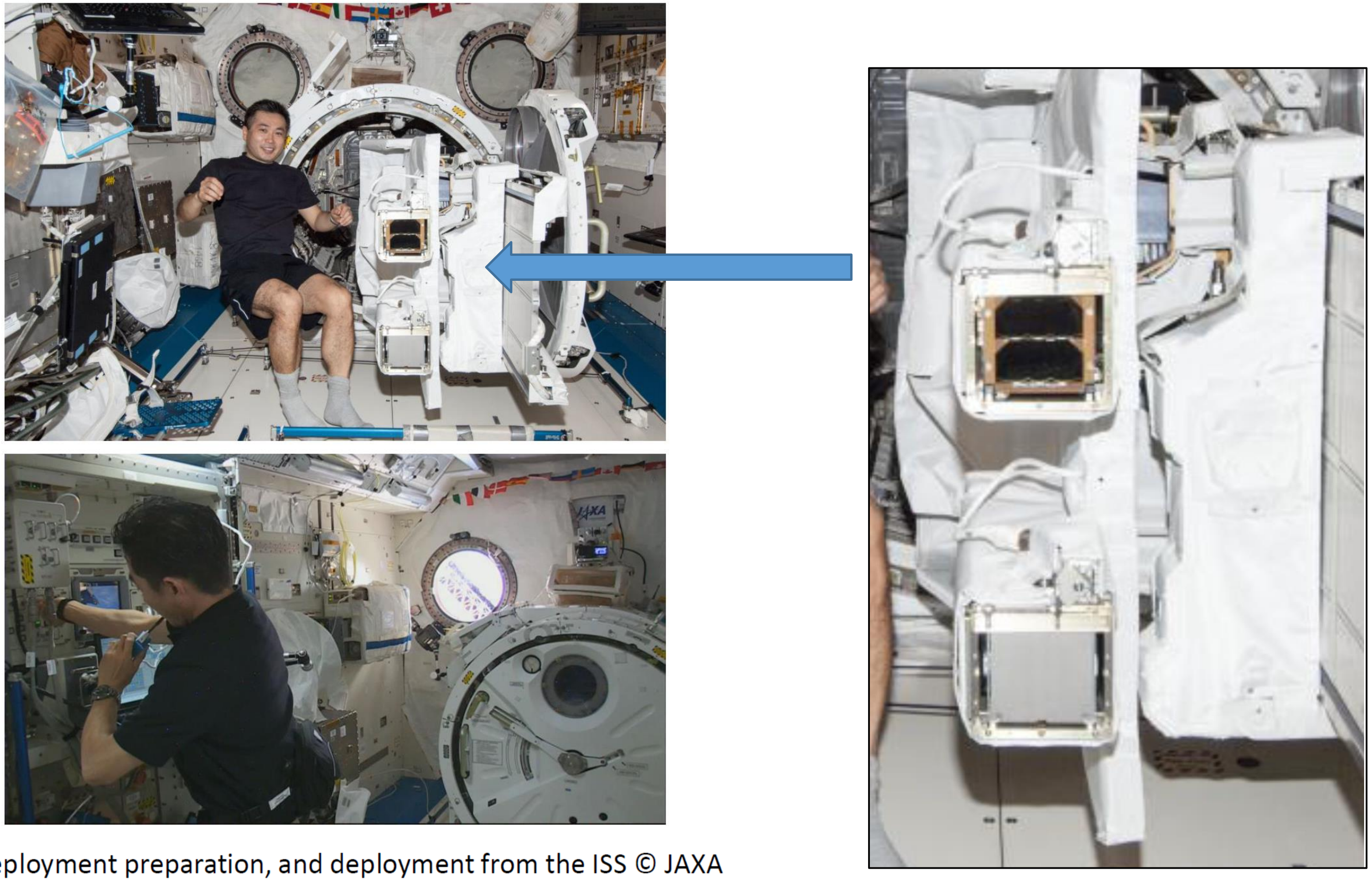
Preparation for Satellite Deployment

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**

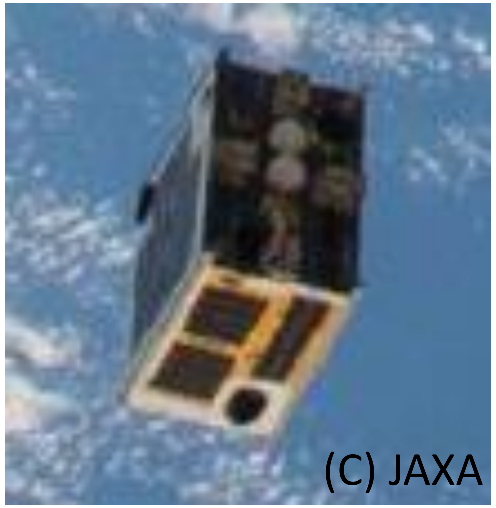
7. Astronaut **triggers the switch** for the deployment



Deployment preparation, and deployment from the ISS © JAXA

5. Launch and First Contact

First Contact and First Light



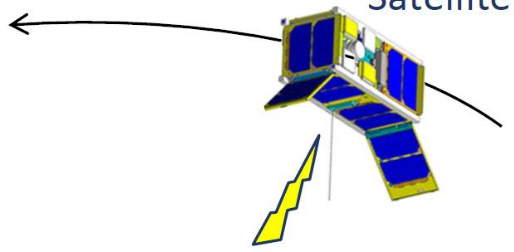
DIWATA-1 (2016, 52.4kg)

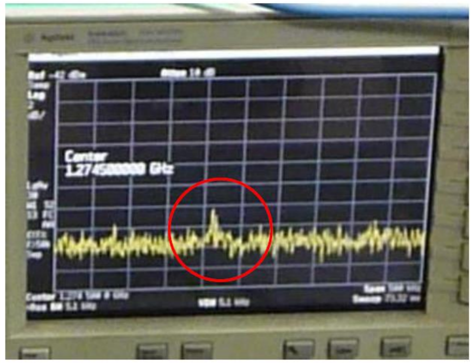
First Contact and First Light

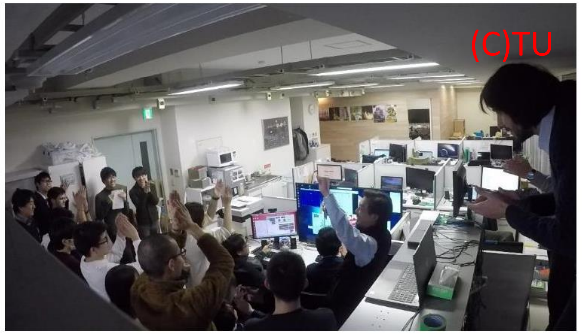
8. CubeSats **automatically start** the functions in space, including **RF transmission**

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

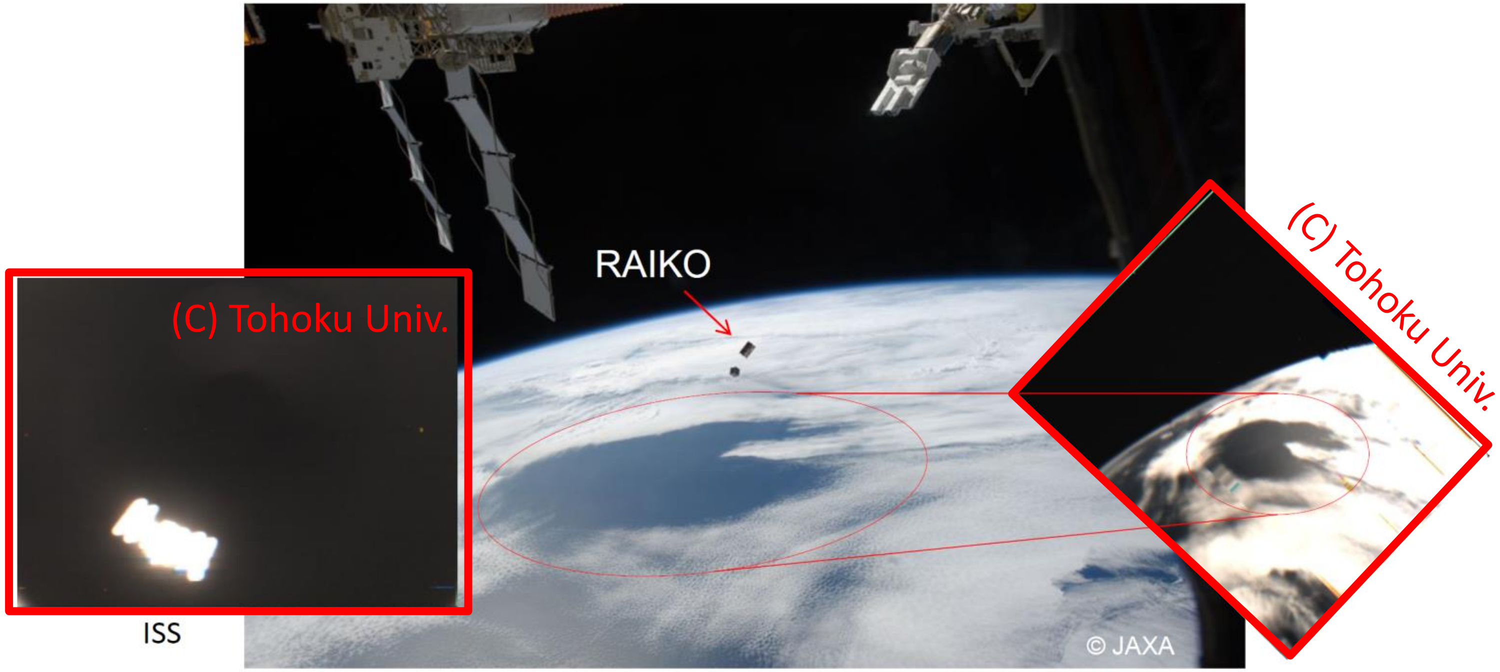
First Contact and First Light

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**



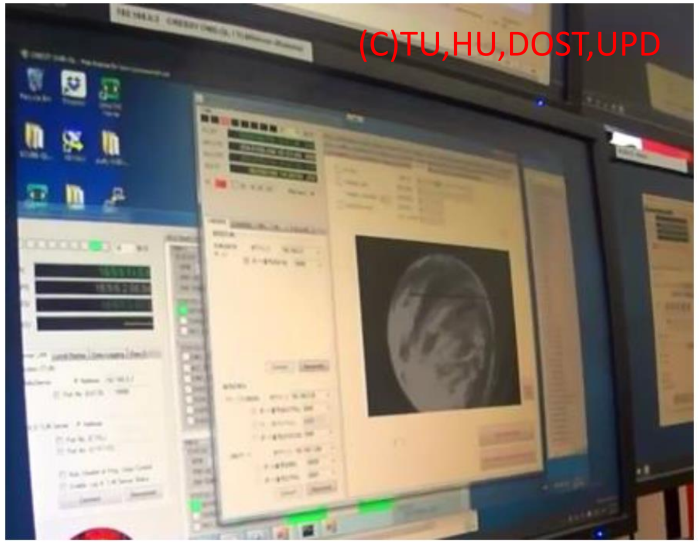
Images obtained by CubeSat RAIKO just after the deployment from the ISS

1st light images by RAIKO

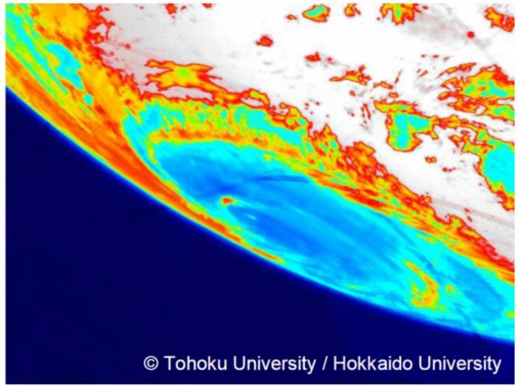
6. Mission Operations

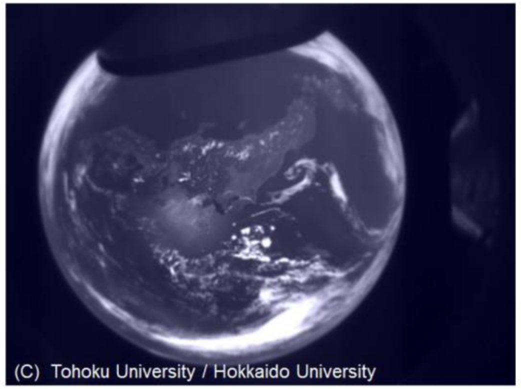
6. Mission Operations

Upload Commands and Download Telemetry Data



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





6. Mission Operations

Software for Realtime Monitor

- 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)

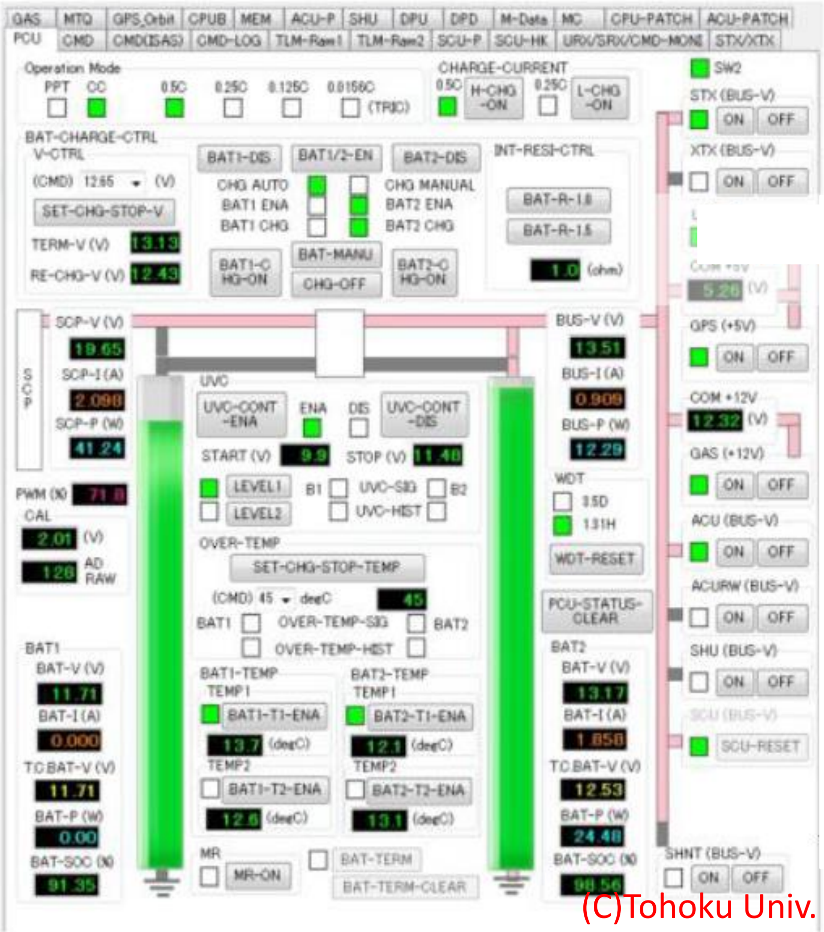
- **battery** charge/discharge (BAT-V, I, P) & **temperature** (BAT-T)

- **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

Method of Stored Commands

- **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

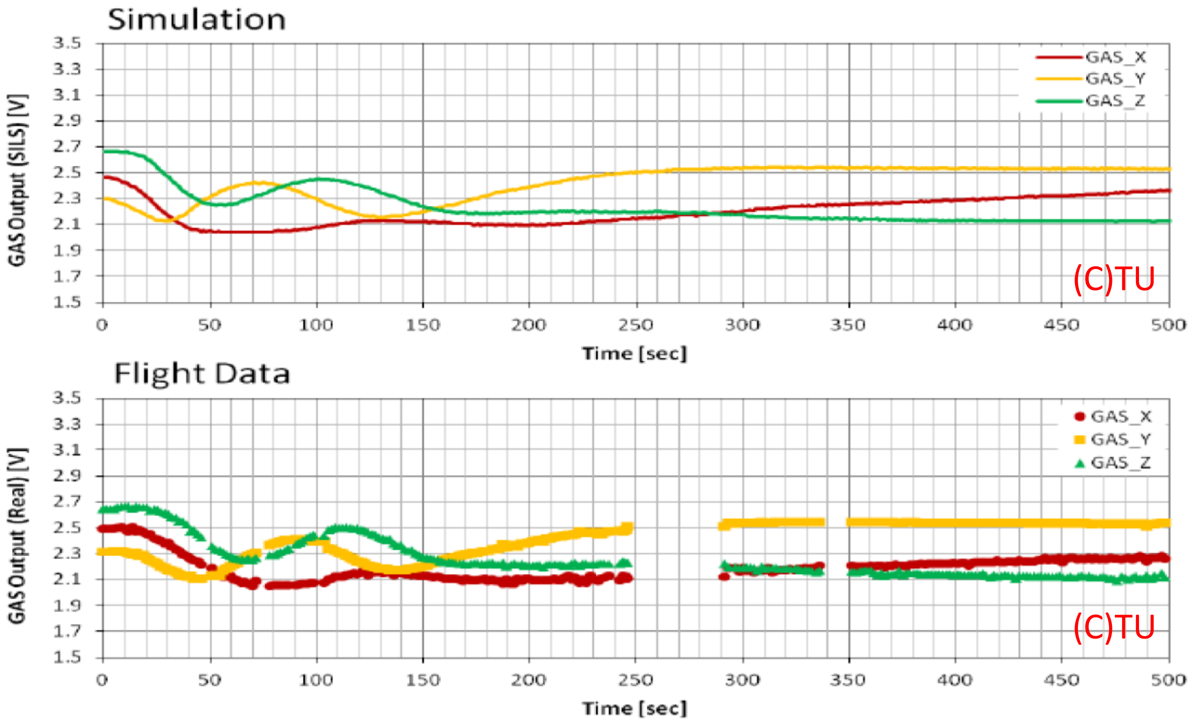
AB CD EF **01 01** ..
AB CD EF **02 02** ..
AB CD EF **03 00** ..
AB CD EF **04 00** ..

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

upload to satellite

Sensor Calibration - Magnitude and Direction

- 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

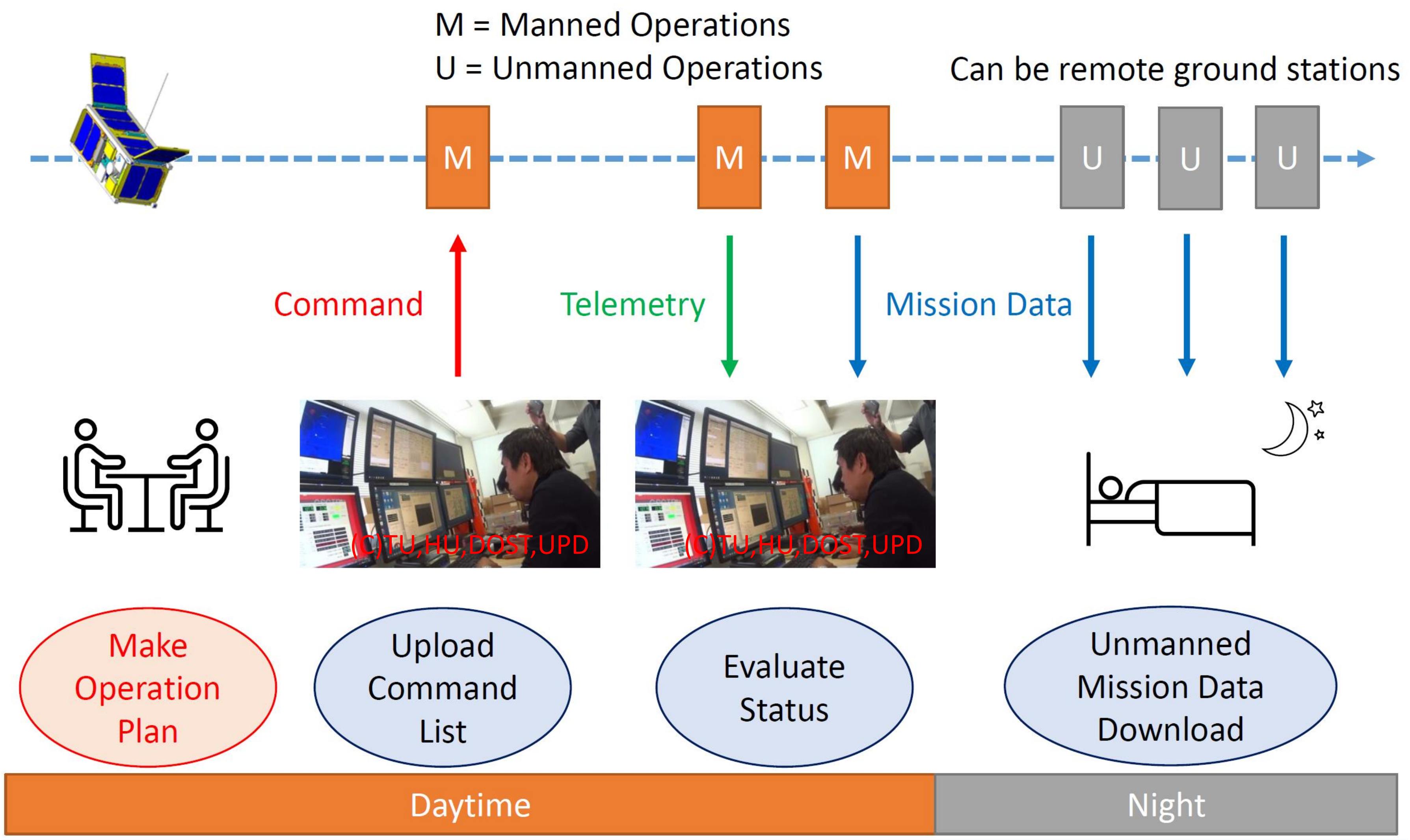


Analysis through comparison of simulation and flight data

3-axis magnetic sensors

6. Mission Operations

Operation Routine



7. Flight Data Analysis

7. Flight Data Analysis

Importance of Housekeeping Data

- Operator must check if the satellite is safe or in trouble
- The satellite condition is understood by housekeeping data include voltage, current, temperature
- Important status should repeat in short periods without requests, and detailed status can be downloaded by request command
- CW beacon link with slow data speed is prepared for a low quality communication link

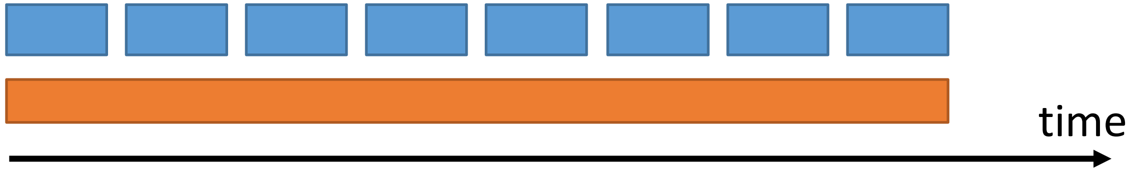
Confirm:
safe or trouble

Housekeeping (HK)
data
via normal data link
or CW beacon

HK include
- voltage, current, temperature (of component, structure)
- mode/parameter settings
- attitude measurements and calculations

important HK
(repeat in short periods)

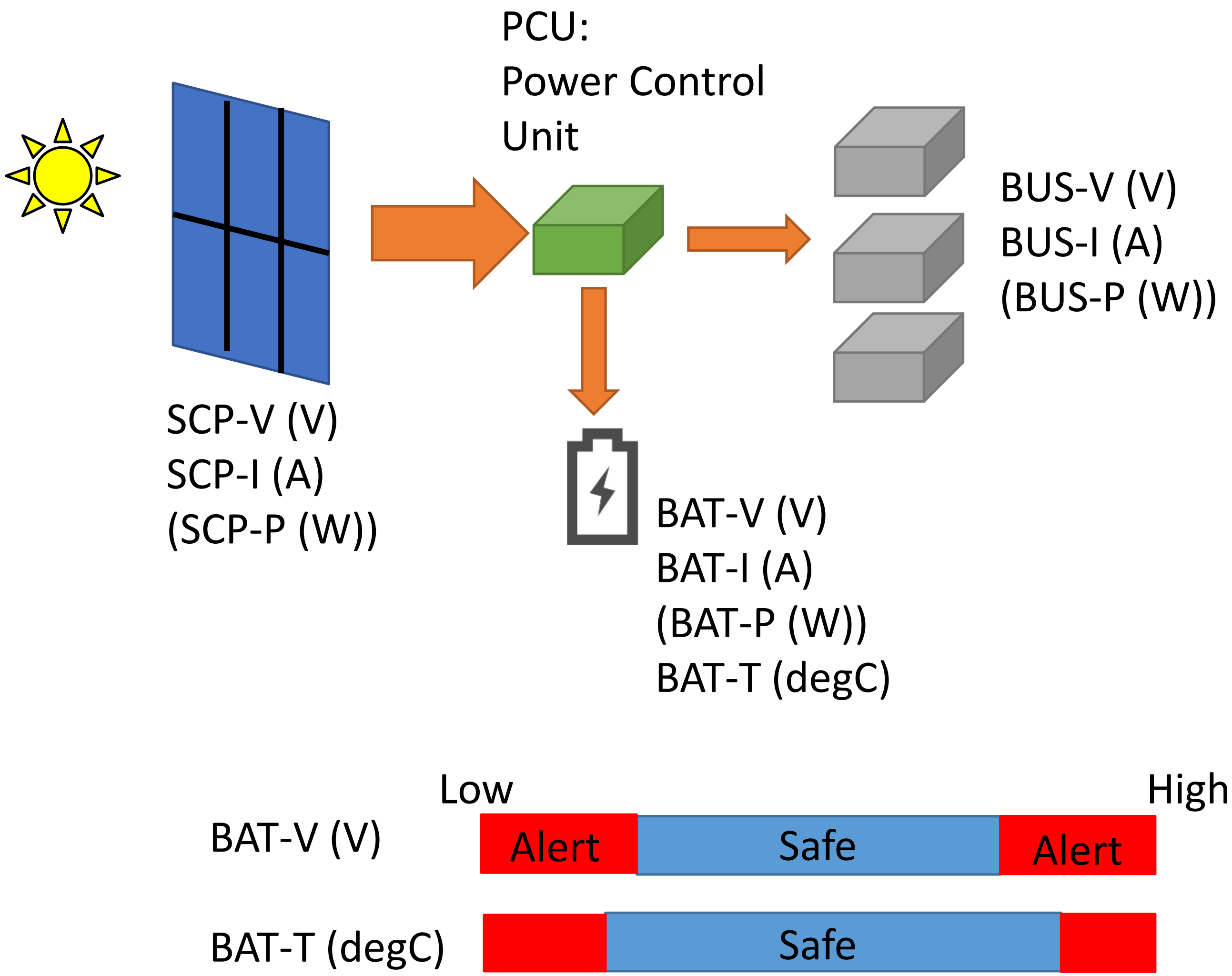
detail status
(spend long period for 1 data set)

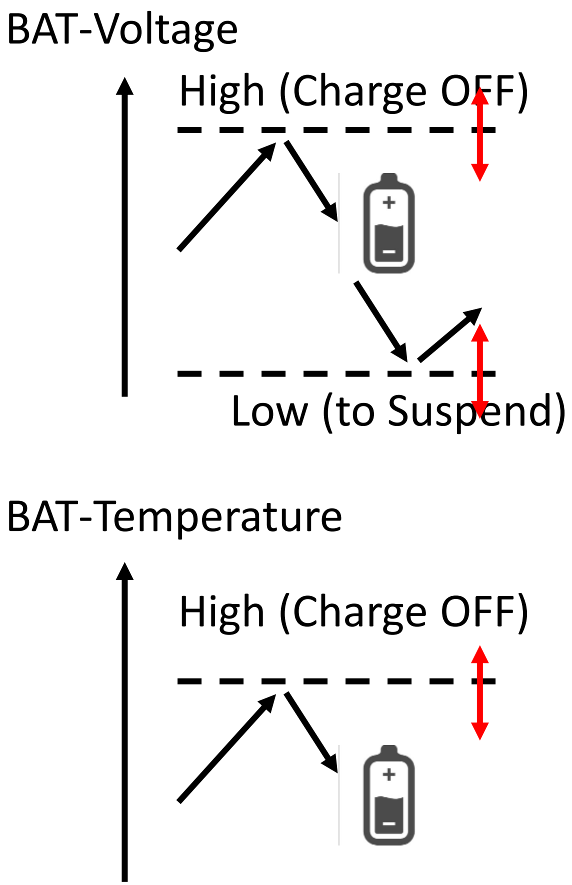


7. Flight Data Analysis

Power Status - Voltage, Current

- Power generation by solar cells, battery and bus components status are the most important HK
- Operator can rapidly notice errors by automatic alerts when the status value is over than expected safety range
- Threshold values for charge stop and suspend mode start will be adjusted by commands



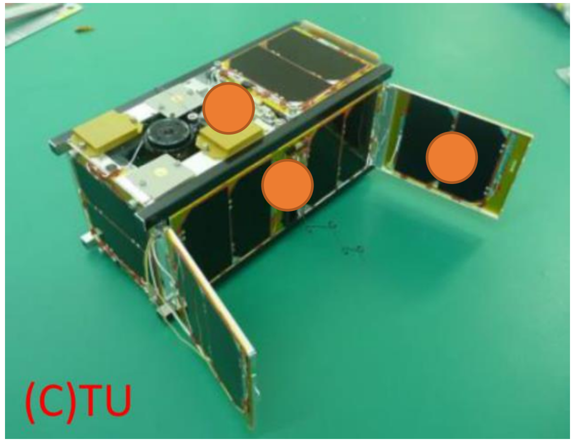


[!] **threshold values** adjusted by commands

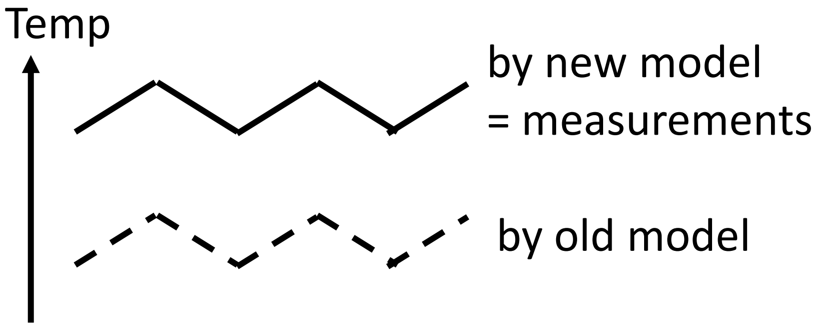
7. Flight Data Analysis

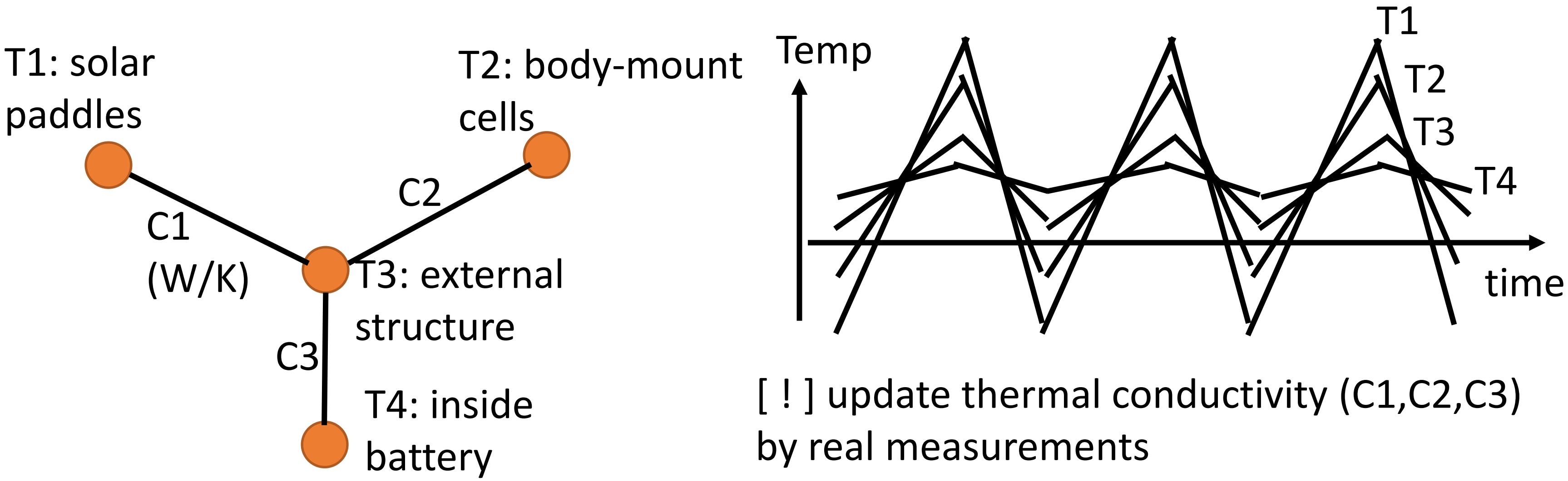
Thermal Status - Temperature of Components and Structure Parts

- Temperature measurements are important in trouble (anomaly) detection and updates of thermal analysis model
- Some parts of the satellite are thermally insulated, these conductivity values can be determined by real temperature measurements



Temperature measurements
=> improve thermal analysis model



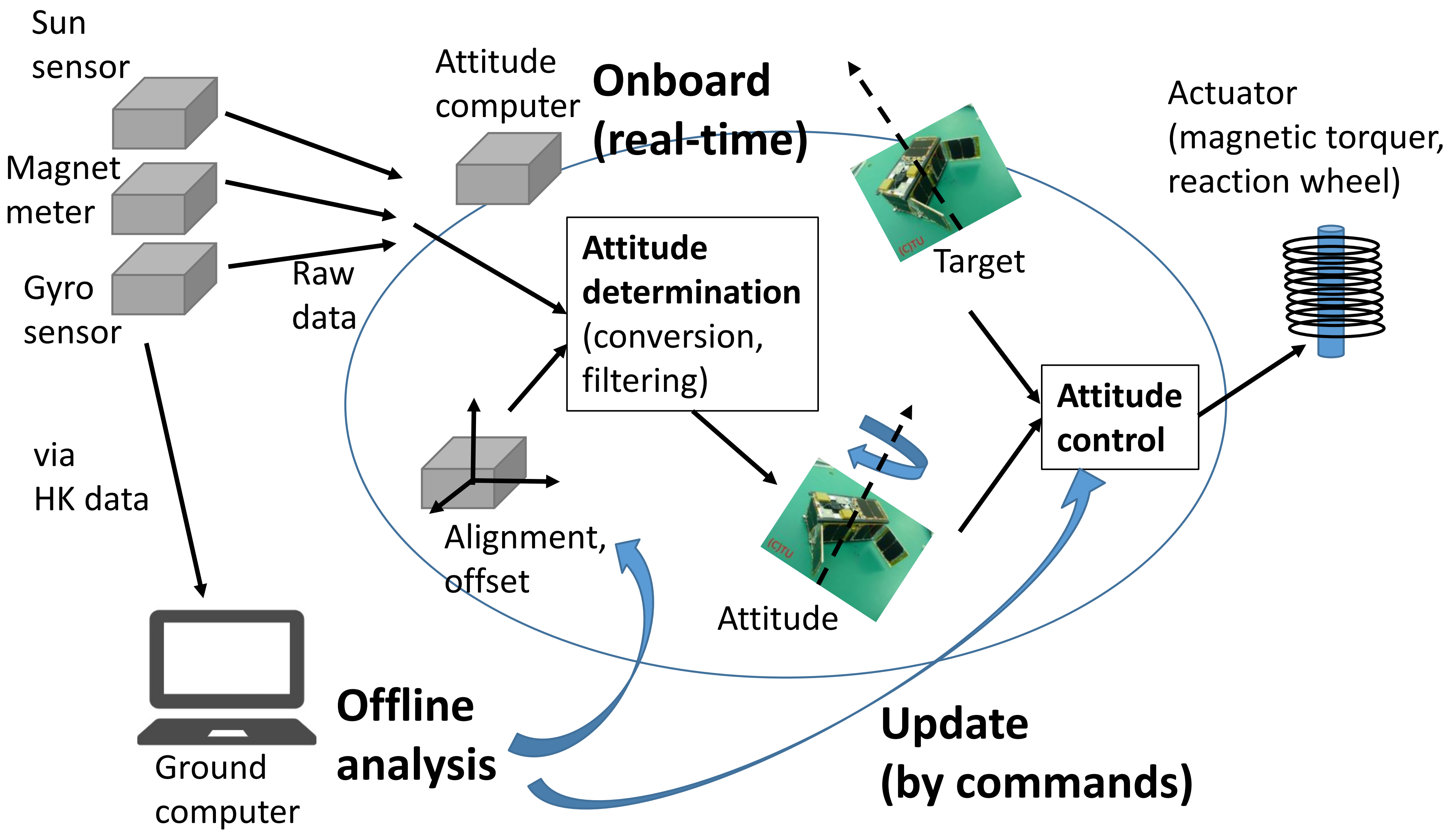


[!] update thermal conductivity (C1,C2,C3) by real measurements

7. Flight Data Analysis

Attitude Status - Sensors of Sun, Magnetic Fields, and Gyro

- Onboard attitude computers calculate the attitude and control it in real-time
- Ground computers will analyze the raw sensor data in HK telemetry, and modify the sensor alignment and control gains by more detailed methods
- Updated settings will be sent to satellite to refine the performance

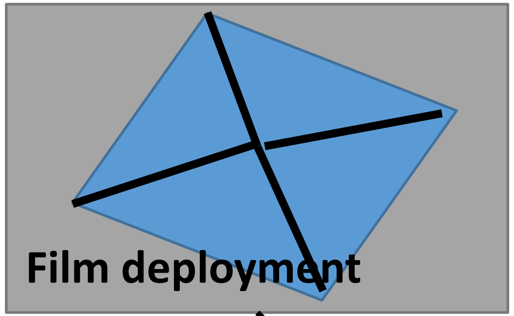


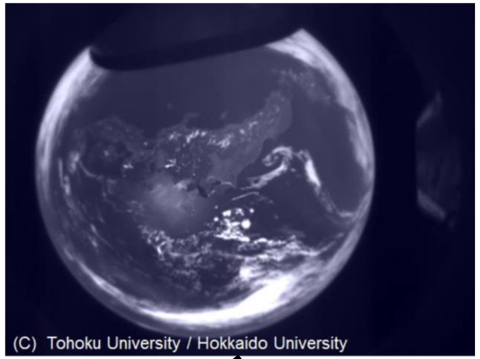
7. Flight Data Analysis

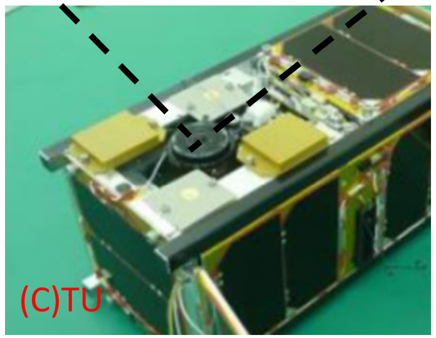
Types of Imaging Data

- For success of the deployment mechanism and attitude control, image data can be the best proof
- Sensor data only evidence is insufficient

- High resolution images will take a lot of download time. it's better to have the function of thumbnail image generation.

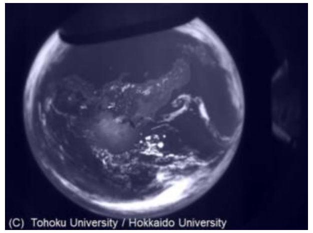




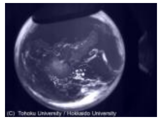


Thumbnail images

1/4



1/8



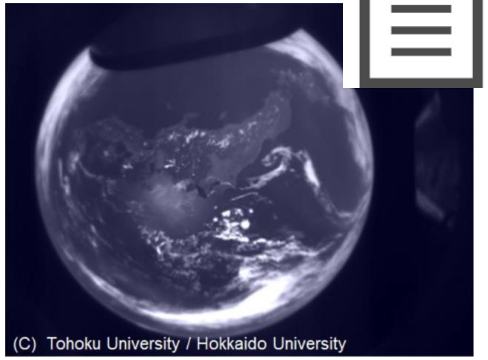
Images definitely prove its success

7. Flight Data Analysis

Importance of Image Meta Data

- Not only image data, status data (time, orbit, attitude, sensor) should be included in image files as meta data.
- Separated files of house-keeping status, detail attitude status, and image files will be difficult and complex to analyze to analyze together on the ground.

Single image file



Pixel color (R,G,B,..)

Camera settings

Observation time

Orbit (estimation or GPS)
attitude (estimation, target)

Attitude sensors
(Sun, magnetic field, gyro)

Image data

Meta data

Onboard real-time estimation

Compare

Used for offline detail analysis at ground

Separated status files
=> complex to analyze

8. Conclusion

8. Conclusion

Section 1-6

- **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.

8. Conclusion

Section 7

- The **Satellite condition** is understood by **housekeeping data** include **voltage, current, temperature**
- **Power generation** by solar cells, **battery** and bus status are the **most important HK**
- **Temperature measurements** are important for **update of thermal analysis model**
- **Onboard attitude** computer calculations should be **updated by detailed analysis on the ground**
- For **success** of **deployment mechanism** and **attitude control**, **image data** can be the **best proof**
- Not only image data, **status data (time, orbit, attitude, sensor)** should be **included in image files as meta data**.

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.