Day #1 01.14 21:00~23:00 (JST)

# KiboCUBE Academy

## Lecture 1-1

# CubeSats Change the World

Tohoku University

Department of Aerospace Engineering

Associate Professor Dr. –Ing. Toshinori Kuwahara

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

JAXA

UNISEC University Space Engineering Consortium JAPAN

United Nations Office for Outer Space Affairs ★ Japan Aerospace Exploration Agency
Kibo CUBE

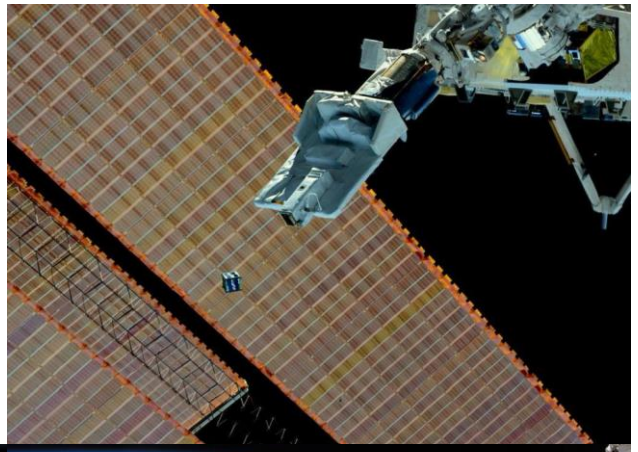
# Contents

# 1. Introduction to Space Technologies and Utilization

# 1. Introduction to Space Technologies and Utilization

## Access to Space

- Enabling access to space and bringing the benefits of space technology to all countries is important for ensuring the sustainability of future space activities.
- Space technologies affect many areas of our lives and their spin-offs have a vast array of applications here on Earth, ranging from medicine to food security, greatly benefiting our economy and society.
- In space, one can be “Ambitious.” *- JAXA/UNOOSA*



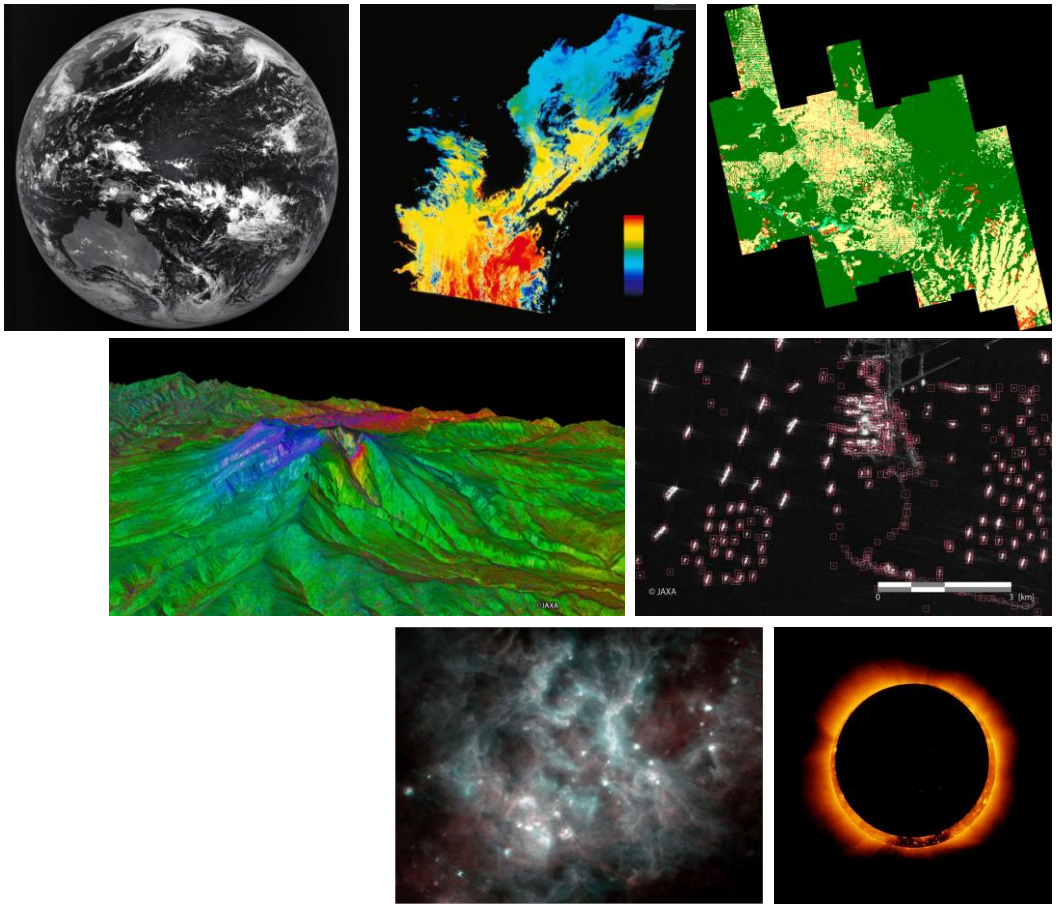
KiboCUBE Launch, Delivery to the ISS, and Deployment from the ISS © JAXA

# 1. Introduction to Space Technologies and Utilization

## Satellite Applications

There are a wide range of satellite application which we benefit from.

- Earth Observation
  - Meteorological Observation
  - Oceanographical Observation
  - Geographical Observation
  - Coastal Area Observation
  - Atmospheric Observation
  - Disaster Monitoring and Prevention
- Communication
  - Satellite Broadcasting
  - Telephone, Internet, etc.
- Navigation
  - Global Navigation Satellite System
  - Traffic: Air, Land, Water, Railroad, etc.
- Science
  - Astronomical
  - Microgravity Experiments: Medicine, Pharmacy, Biology, Material Science, etc.
  - Moon, Asteroids, Planets, and Deep Space Exploration.

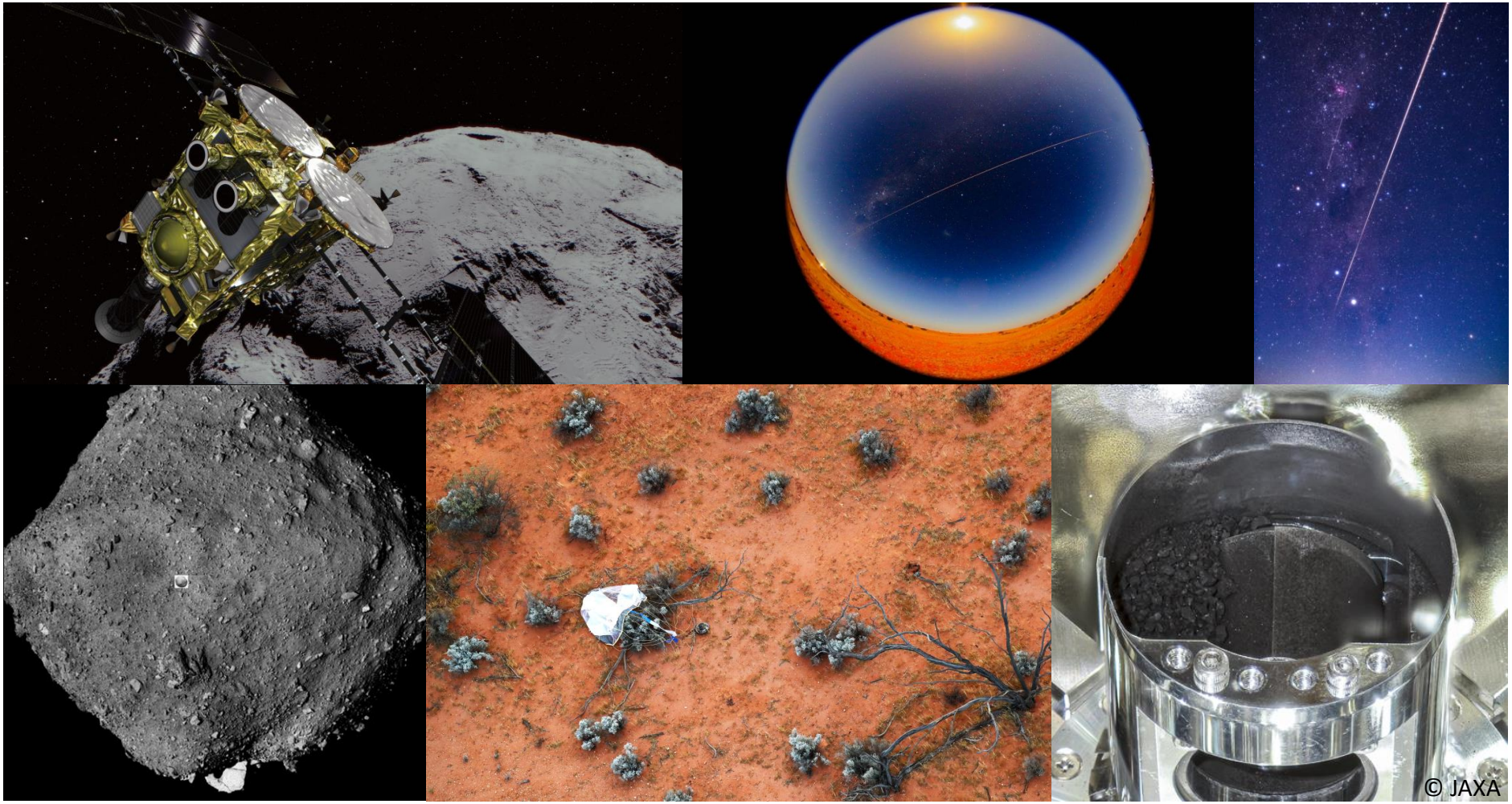


© JAXA

# 1. Introduction to Space Technologies and Utilization

## Space Exploration

- Asteroid Sample Return Mission – *Hayabusa-2*

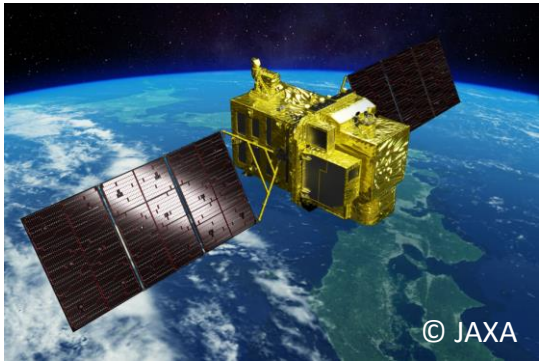
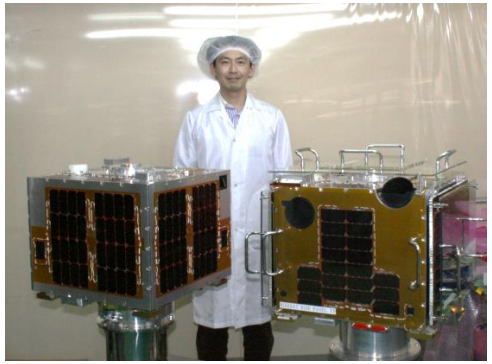


# 2. Emerging Technologies of Small Space Systems

# 2. Emerging Technologies of Small Space Systems

## Characteristics of Small Space Systems

Comparison between large and small satellites:

| Large Satellite | | Small Satellite |
|---|---|---|
|   | |  |
| **Large** | Mass | **Small** |
| **High** | Cost | **Low** |
| **Long** | Development Time | **Short** |

- Dedicated launch
- Need high-reliability, low-risk
- High-performance, Low observation frequency

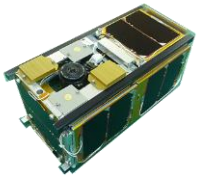
- Small mass = Frequent launch opportunities
- Low cost = Can try challenging missions, realize large constellations/networks (Frequent Observations)
- Rapid Development = Can utilize brand new technologies
- Suitable platform for space education and rapid technology demonstration

# 2. Emerging Technologies of Small Space Systems

## Mass Categories

Small, Micro, Nano, and Pico-satellites.

*CubeSat*

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Pico-Satellite

Nano-Satellite

Micro-Satellite

Small/Medium Satellite

0kg 1kg 10kg 100kg 1000kg

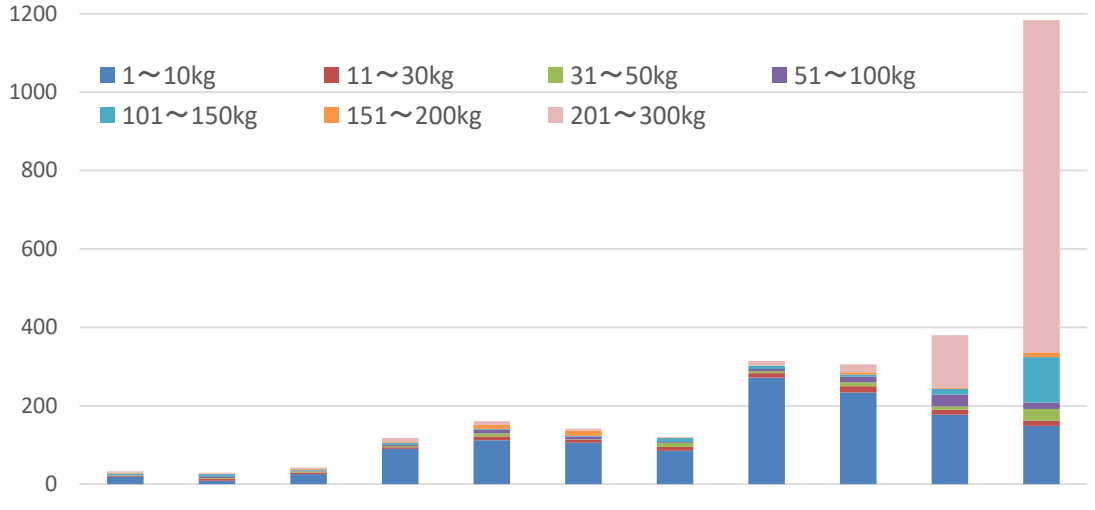
# 2. Emerging Technologies of Small Space Systems

## Accelerating Utilization of Small Space Systems

- The number of small satellites smaller than 300kg is rapidly increasing.
- Large portion of them are in mega-constellations of telecommunication satellites.

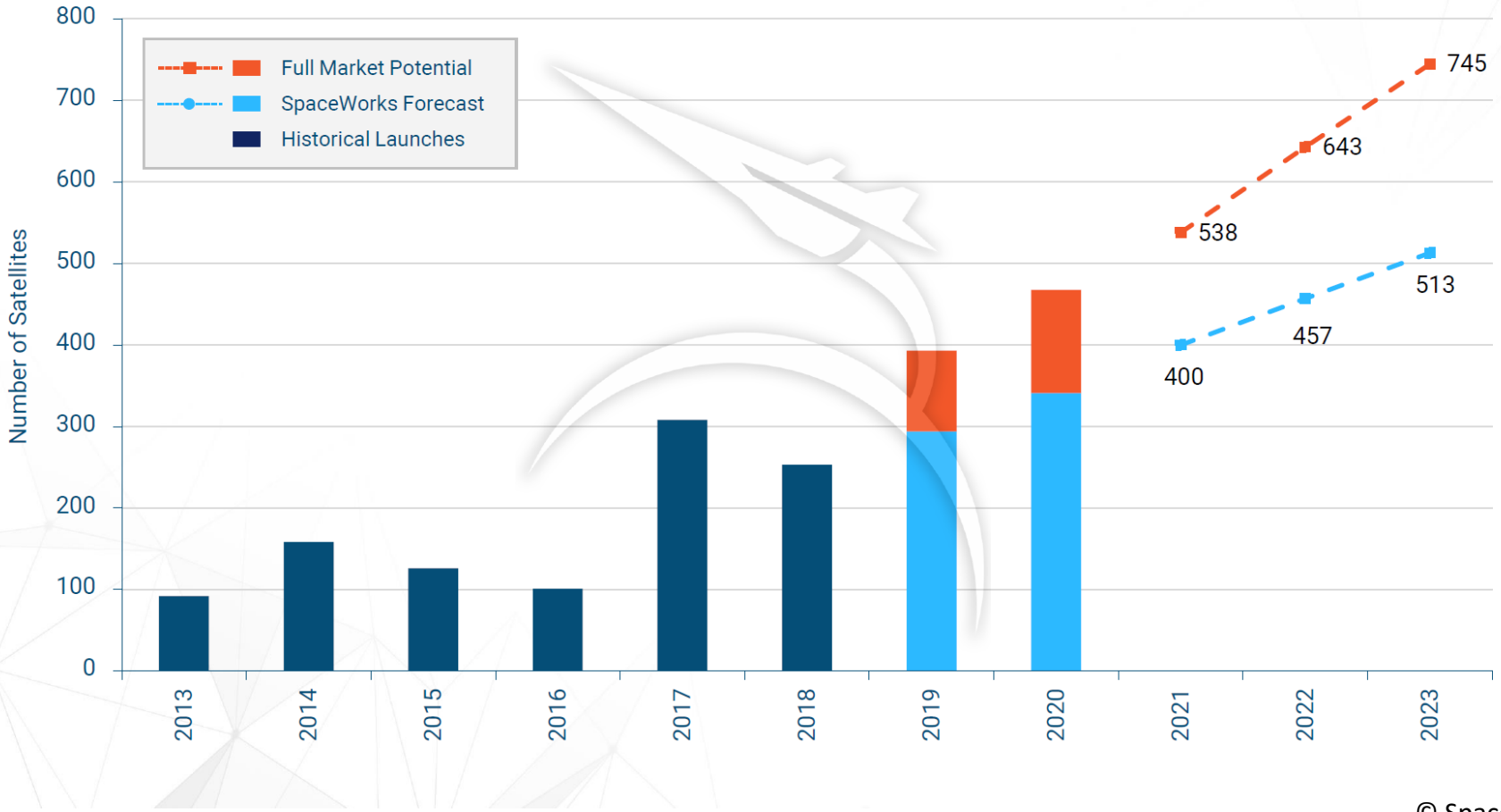
### Launches of Small Satellites (1~300kg)

(Successful Launches Only)




| | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1～10kg | 19 | 9 | 26 | 90 | 112 | 106 | 85 | 272 | 234 | 177 | 149 |
| 11～30kg | 2 | 5 | 4 | 4 | 10 | 7 | 10 | 11 | 16 | 13 | 13 |
| 31～50kg | 1 | 2 | 3 | 3 | 8 | 1 | 11 | 5 | 10 | 8 | 30 |
| 51～100kg | 1 | 4 | 2 | 4 | 9 | 7 | 2 | 6 | 14 | 31 | 16 |
| 101～150kg | 4 | 6 | 2 | 4 | 2 | 2 | 10 | 8 | 6 | 14 | 116 |
| 151～200kg | 2 | 1 | 2 | 2 | 10 | 13 | 1 | 1 | 5 | 2 | 12 |
| 201～300kg | 4 | 2 | 4 | 11 | 10 | 6 | 1 | 11 | 21 | 135 | 848 |
| Total | 33 | 29 | 43 | 118 | 161 | 142 | 120 | 314 | 306 | 380 | 1184 |

### Nano/Microsatellites (1 – 50 kg)

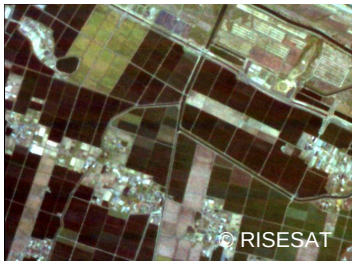


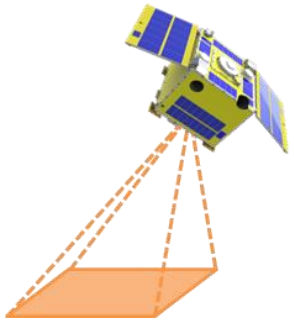
# 2. Emerging Technologies of Small Space Systems

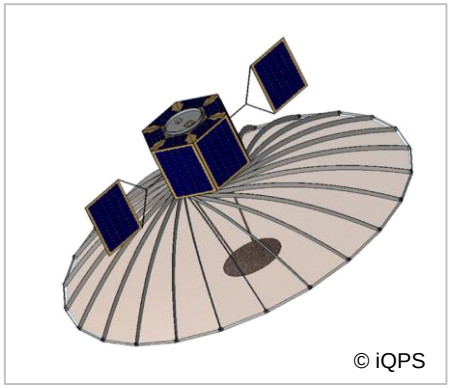
## Advanced Applications of Micro-satellites

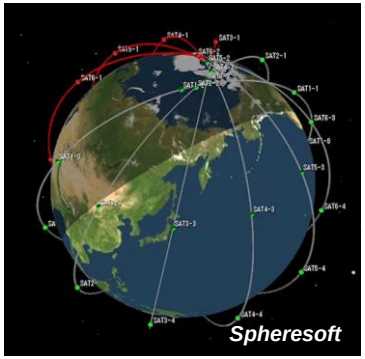
There are a wide range of applications for micro-satellites.

- Earth Observation
  - Optical observation
  - SAR (Synthetic Aperture Radar)
  - Radio signals measurement
- Communication
  - Internet communication
  - M2M (Machine-to-Machine) communication
  - AIS (Automatic Identification System)
  - High-speed laser communication
- New technologies
  - Debris removal
  - Re-entry and return capsule
  - On-orbit servicing
  - Artificial shooting stars
- Science
  - Astronomical, Space weather
  - Moon, Asteroids, Planets, and Deep Space Exploration.

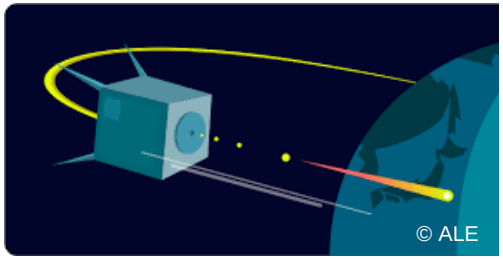


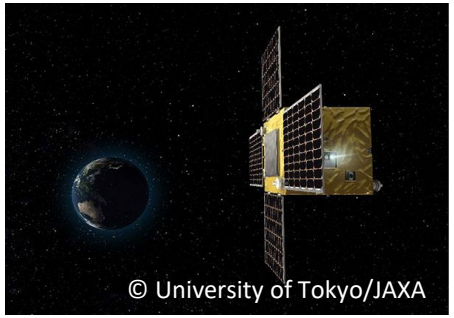





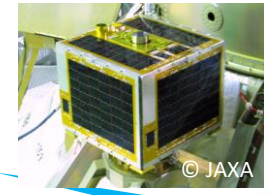




# 2. Emerging Technologies of Small Space Systems

## Exemplary Small Satellite Projects at Tohoku University



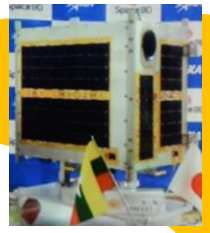

***SPRITE-SAT (2009)***


***RISING-2 (2014)***

***DIWATA-1 (2016)***

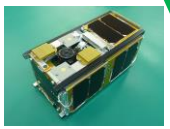
**International Space Education / Collaboration**

***DIWATA-2 (2018)***

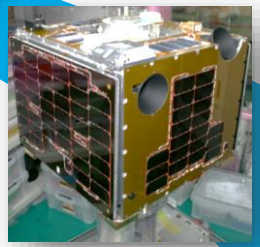


***MMSAT-1 (2020)***

**Nano-satellites**

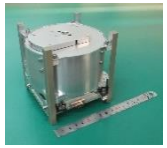


***RAIKO (2012)***



***RISESAT (2019)***

***ALE-1 (2019)***



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***FREEDOM (2017)***

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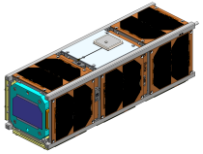
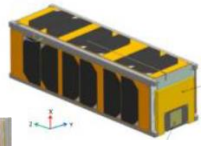
***ALE-2 (2019)***

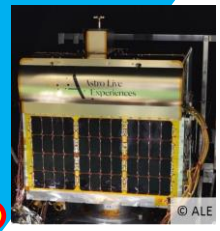


***ALE-EDT***



***BioCube***

**Micro-satellites**

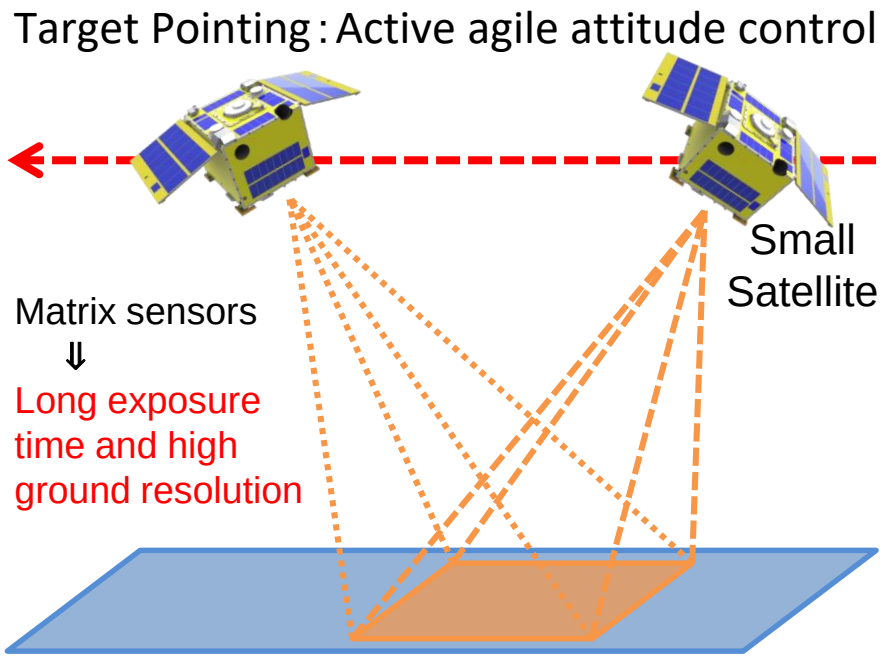


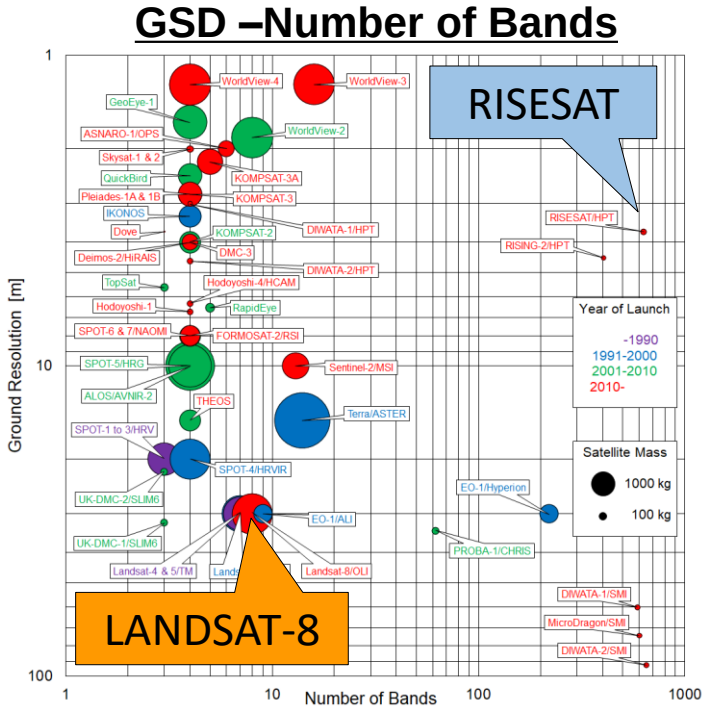

***ALE-3***

# 2. Emerging Technologies of Small Space Systems

## Earth Observation – Micro-satellite RISESAT Example

- Demonstration of high-resolution multi-spectral Earth observation.
  - Cassegrain Telescope with 3.7 m ground sampling distance.
  - Liquid crystal tunable filters (LCTF) (420-650nm, 650-1050nm = 630 bands)
- Combined with high-accuracy target pointing attitude control.

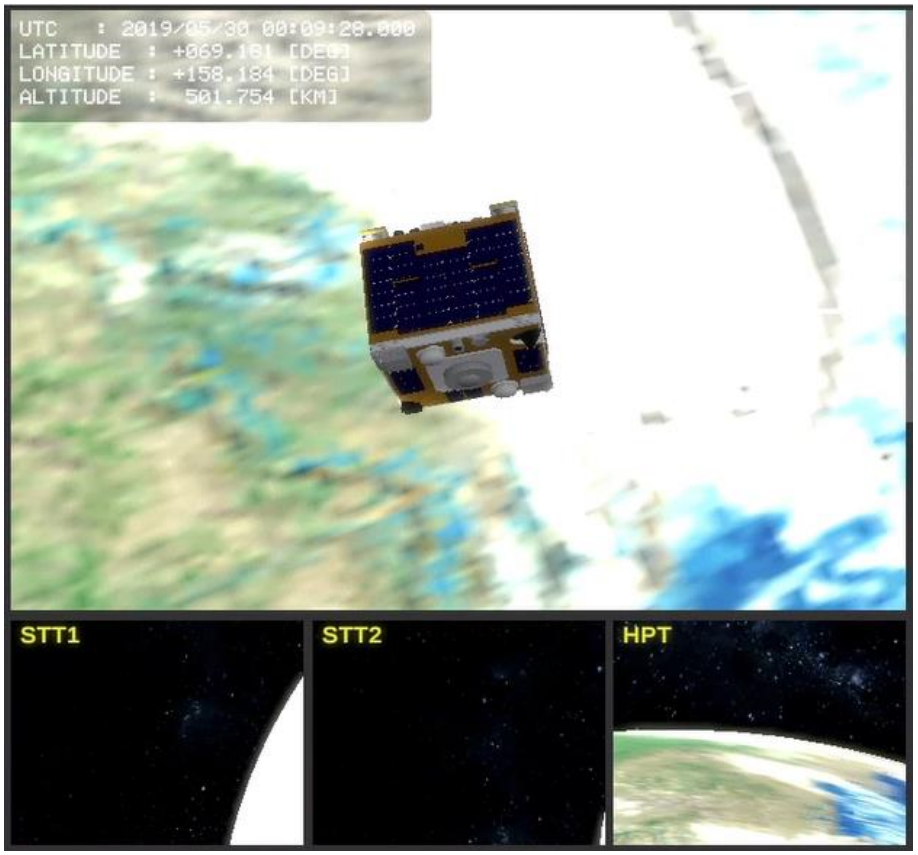



High-resolution, multi-spectral observation.

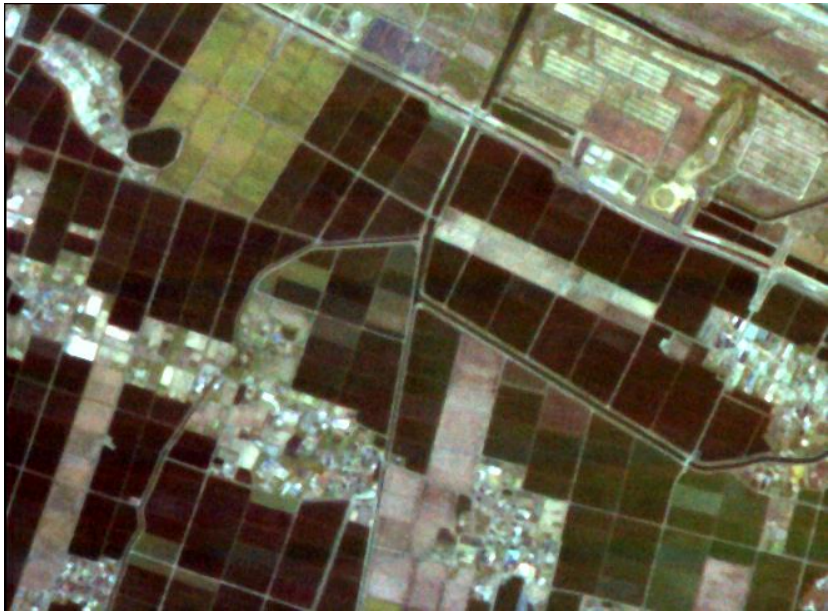
# 2. Emerging Technologies of Small Space Systems

## Earth Observation – Micro-satellite RISESAT Example




2019/05/30 00:09:28 ~ 00:19:02 UTC

- Generated from the actual downlinked log data of attitude determination and control.
- x 50 speed



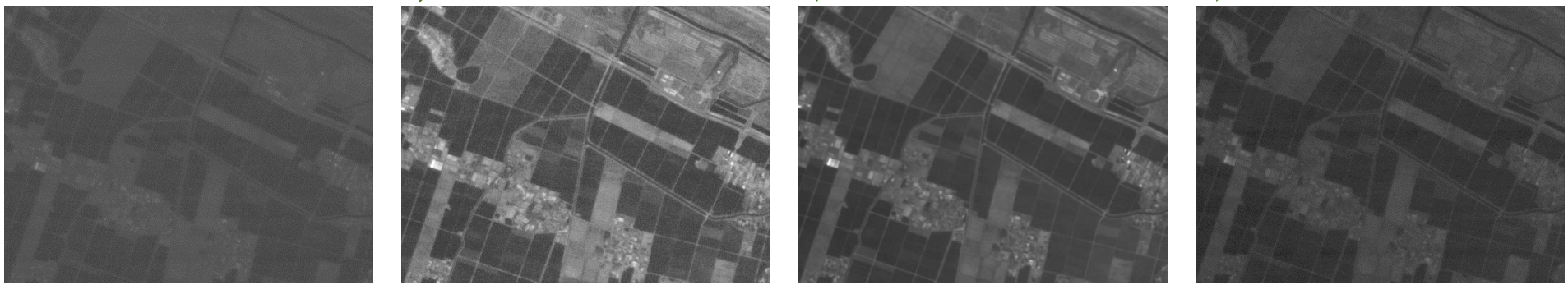
First Light
Sendai (2019/5/30), True Color Composite

- Multi-spectral observation (8 selected bands)
  - 443, 490, 555, 670, 710, 765, 869, 910 nm
- Attitude Control Sequence:
  - Coarse attitude determination and control
  - Inertial pointing with fine attitude determination
  - Target pointing observation

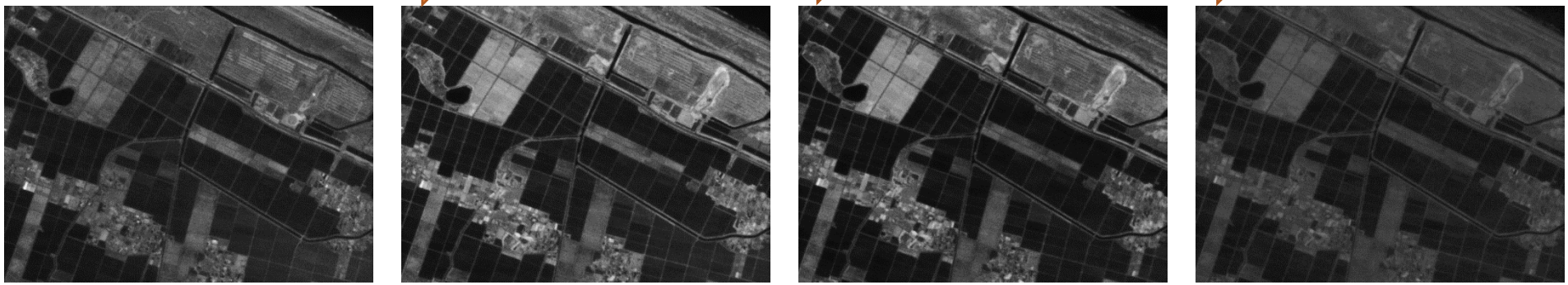
# 2. Emerging Technologies of Small Space Systems

## Earth Observation – Micro-satellite RISESAT Example

VIS 443 nm → 0.5 s → 490 nm → 0.5 s → 555 nm → 0.5 s → 670 nm



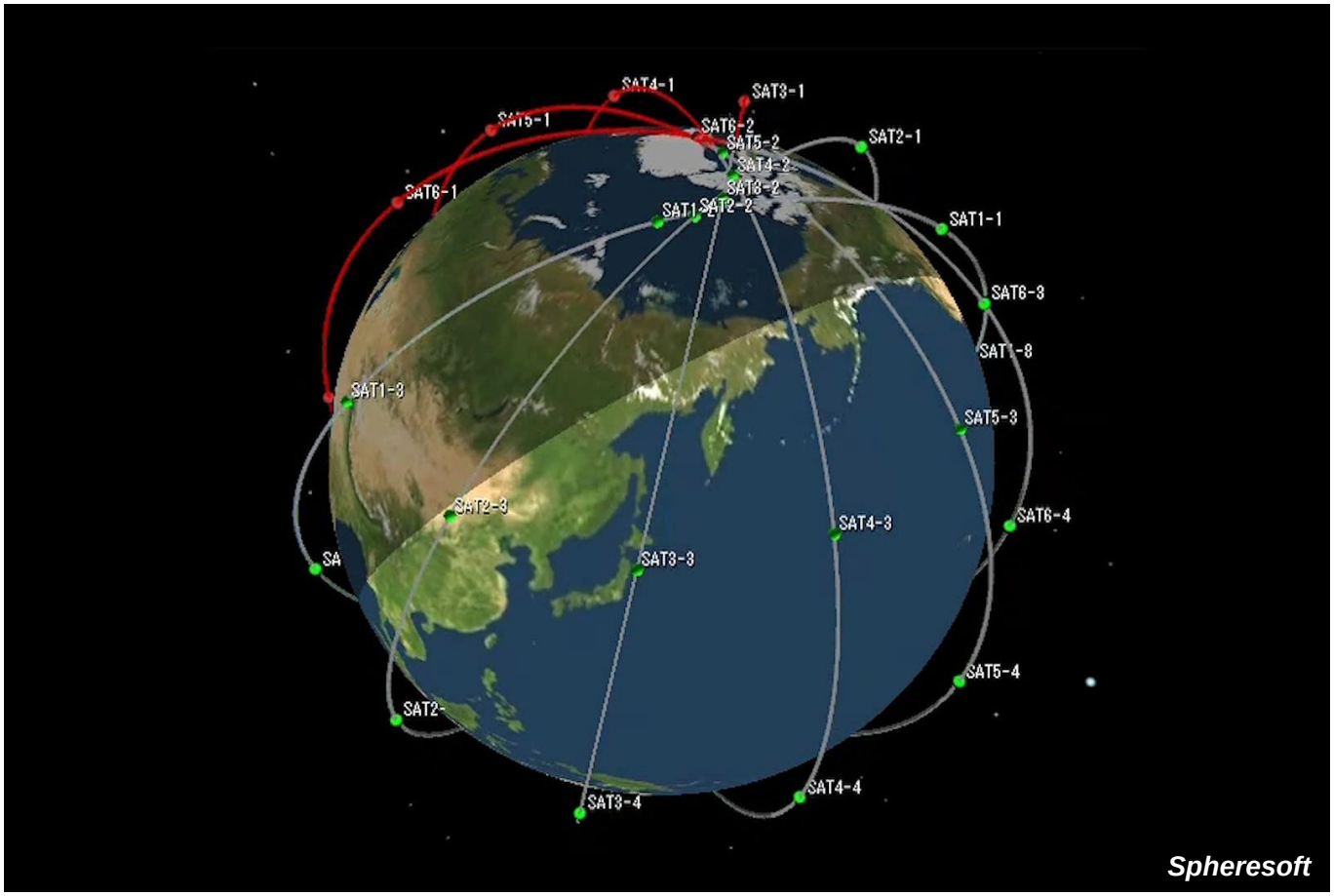
NIR 710 nm → 0.5 s → 765 nm → 0.5 s → 869 nm → 0.5 s → 910 nm

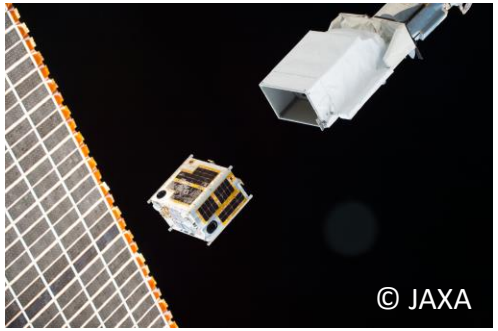


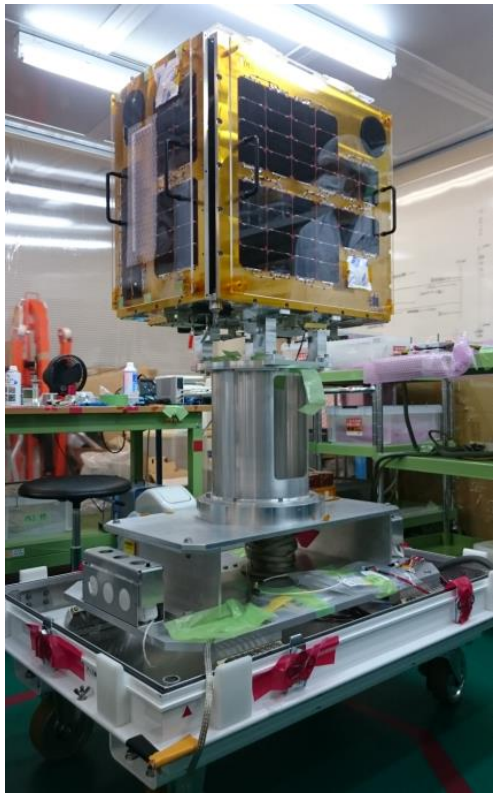
# 2. Emerging Technologies of Small Space Systems

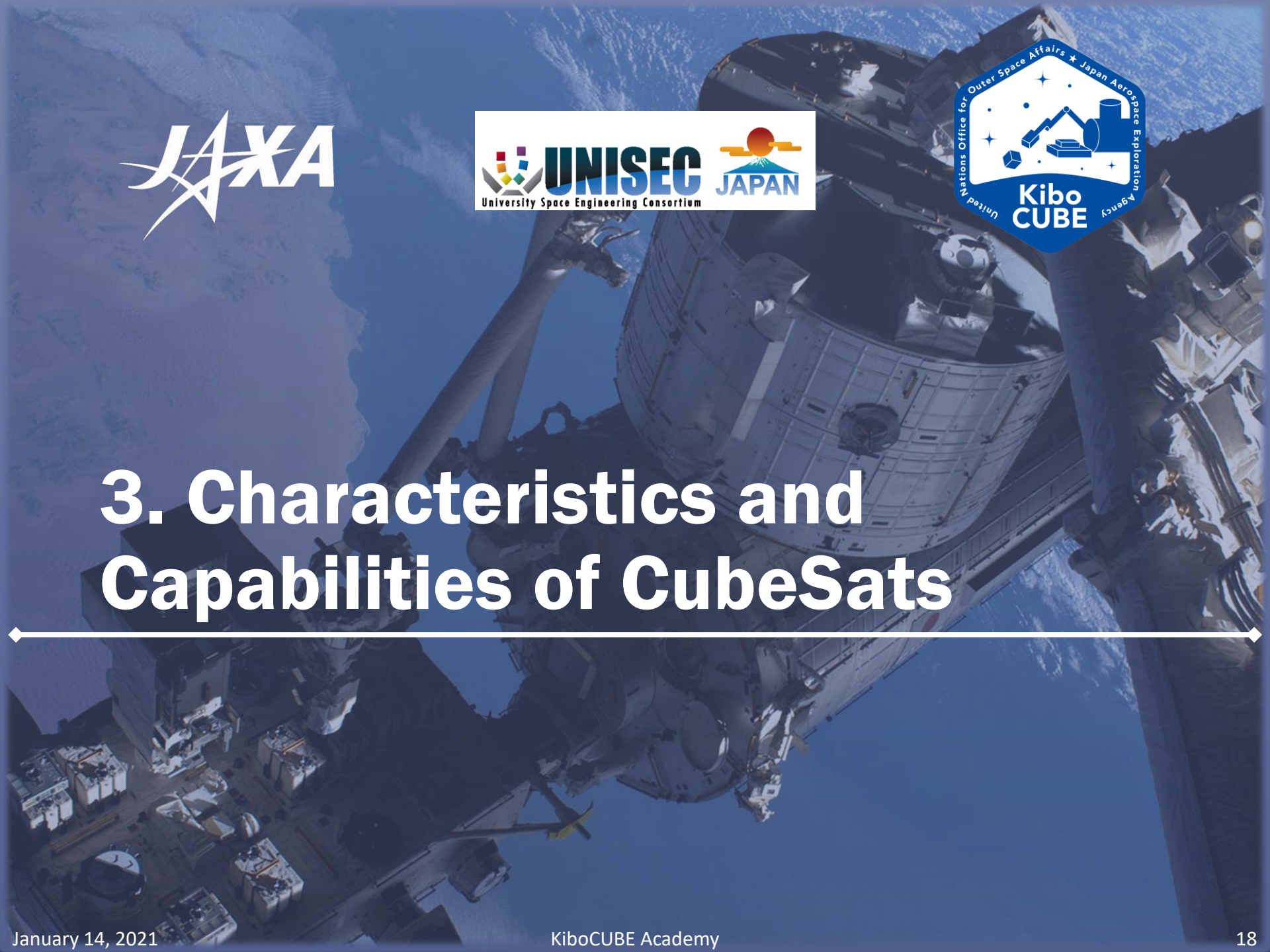
## Small Satellite Constellation

- Thanks to the characteristics of small satellites, they can be operated in a constellation to achieve higher revisit frequencies all over the world.



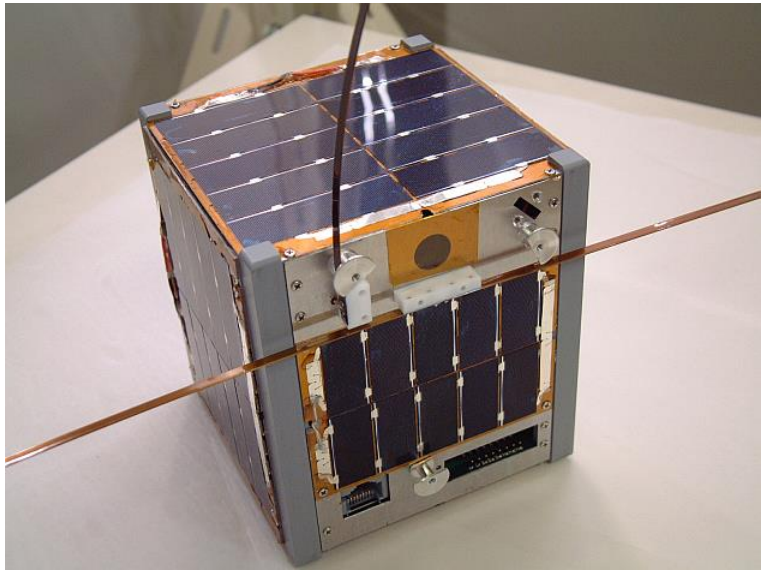


# 3. Characteristics and Capabilities of CubeSats

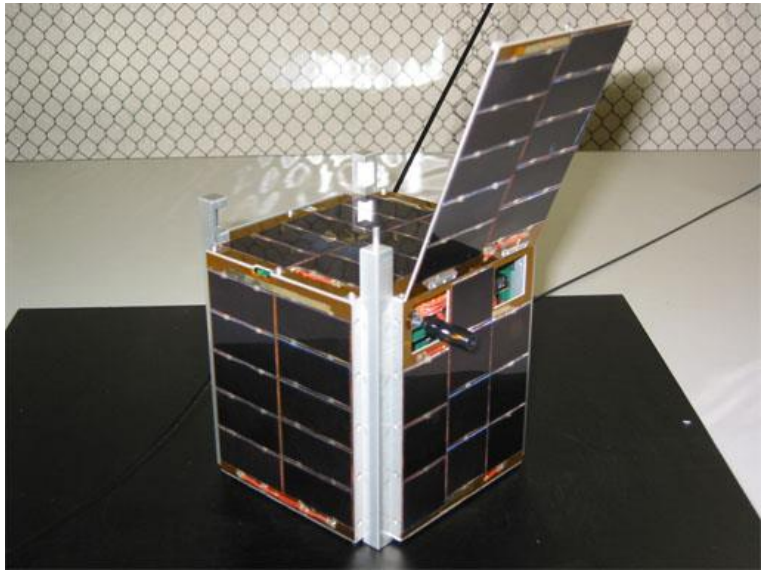
# 3. Characteristics and Capabilities of CubeSat

## What is CubeSat?

- The first CubeSats launched in 2003 were developed by the University of Tokyo (XI-IV) and Tokyo Institute of Technology (CUTE-I), respectively.
- The size, mass, and mechanical interface are standardized. 1 U (Unit) is 10cm x 10cm x 10 cm and 1.33 kg.
- CubeSats are widely used for space education, research, and business in the world.



XI-IV © University of Tokyo

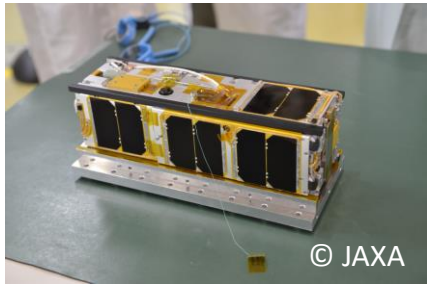


CUTE-I © Tokyo Institute of Technology

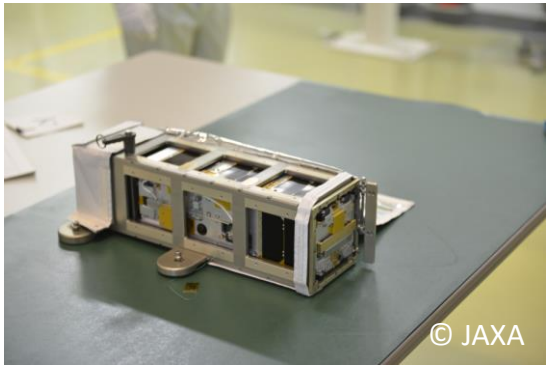
# 3. Characteristics and Capabilities of CubeSat

## Types of CubeSats

- CubeSats are installed in launch and release “pods.”
- There are several different types of CubeSats, listed below:
  - 1U: 1 x 1 x 1 Unit
  - 1.5U: 1 x 1 x 1 Unit
  - 2U: 1 x 1 x 2 Units
  - 3U: 1 x 1 x 3 Units
  - 4U: 1 x 1 x 4 Units
  - 5U: 1 x 1 x 5 Units
  - 6U-long: 1 x 1 x 6 Units
  - 6U-wide: 1 x 2 x 3 Units
  - etc.

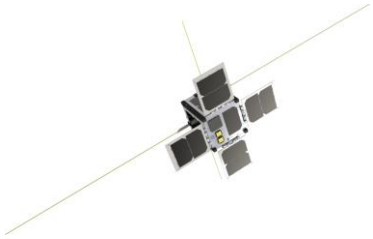


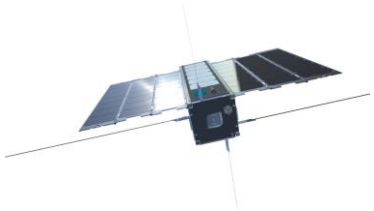

3U CubeSat

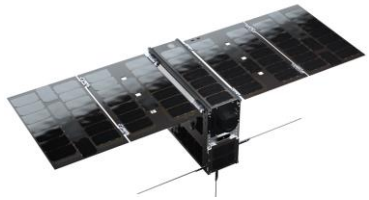



Types of Pods:

- 3U: 1 x 1 x 3 Unit
- 6U-wide: 1 x 2 x 3 Units
- 6U-long: 1 x 1 x 6 Units
- etc.







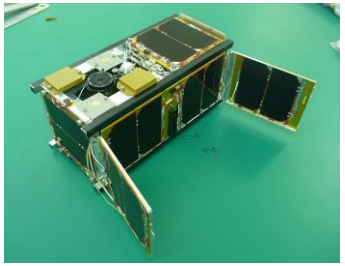
© AAC Clyde Space

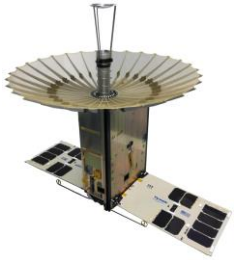
# 2. Emerging Technologies of Small Space Systems

## Advanced Applications of CubeSats

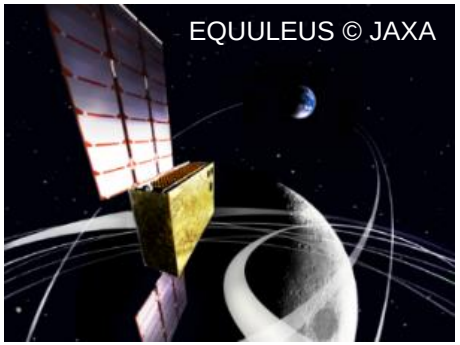
There are a wide range of applications for CubeSats.

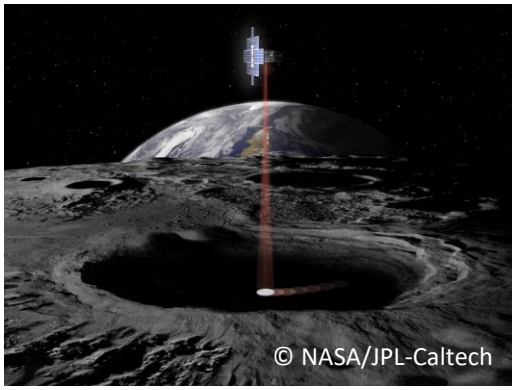
- Earth Observation
  - Optical observation
  - SAR (Synthetic Aperture Radar)
  - Radio signal analysis
  - Weather observation measurement
- Communication
  - Data relay
  - M2M (Machine-to-Machine) communication
  - AIS (Automatic Identification System)
  - High-speed laser communication
- New technologies
  - GNSS signal occultation measurement
  - Space robotics
  - Electrodynamic Tether
  - Re-entry and return capsule
- Science
  - Astronomy
  - Bioscience experiment
  - Moon, Asteroids, Planets, and Deep Space Exploration.

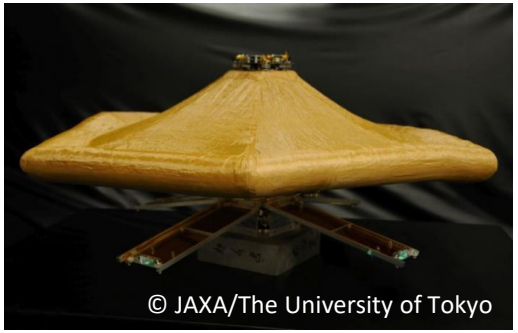


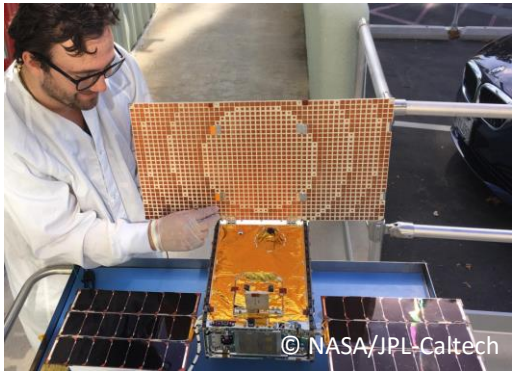



© NASA/JPL-Caltech



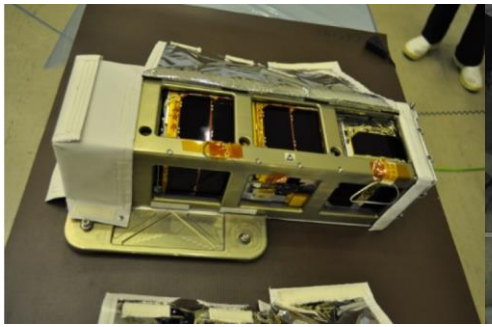



# 4. Launch Opportunities for CubeSats

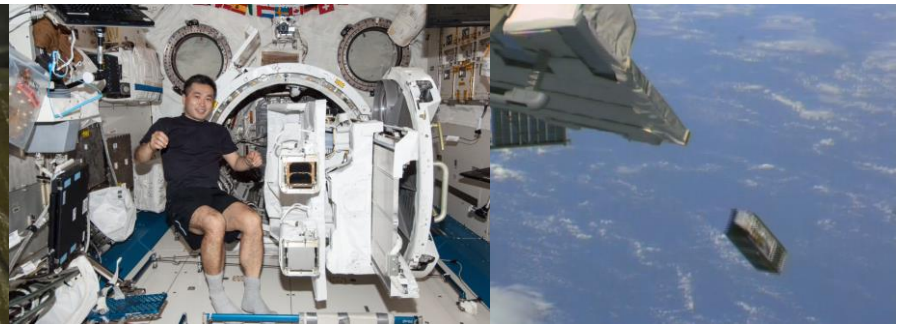
# 4. Launch Opportunities for CubeSats

## KiboCUBE Academy Launch Opportunity

- KiboCUBE Academy provides deployment opportunities from the ISS Kibo
- The possible launch vehicle can be one of the transfer vehicles to the ISS
  - HTV: H-II Transfer Vehicle
  - SpX Dragon: SpaceX Dragon
  - Orbital Cygnus
- The launch environment is different in each vehicle
- CubeSats are installed in the satellite deployment POD (J-SSOD: Japanese Experiment Module (JEM) Small Satellite Orbital Deployer) and stowed inside Cargo Transfer Bag (CTB) with soft packing material.
- Vibration conditions are very mild relative to those encountered during a direct launch.
- Frequent opportunities are provided, up to 4 times per year.
- As the orbit altitude is about 400 km, it is ensured that the CubeSats will re-enter the atmosphere after their mission lifetime without becoming space debris.



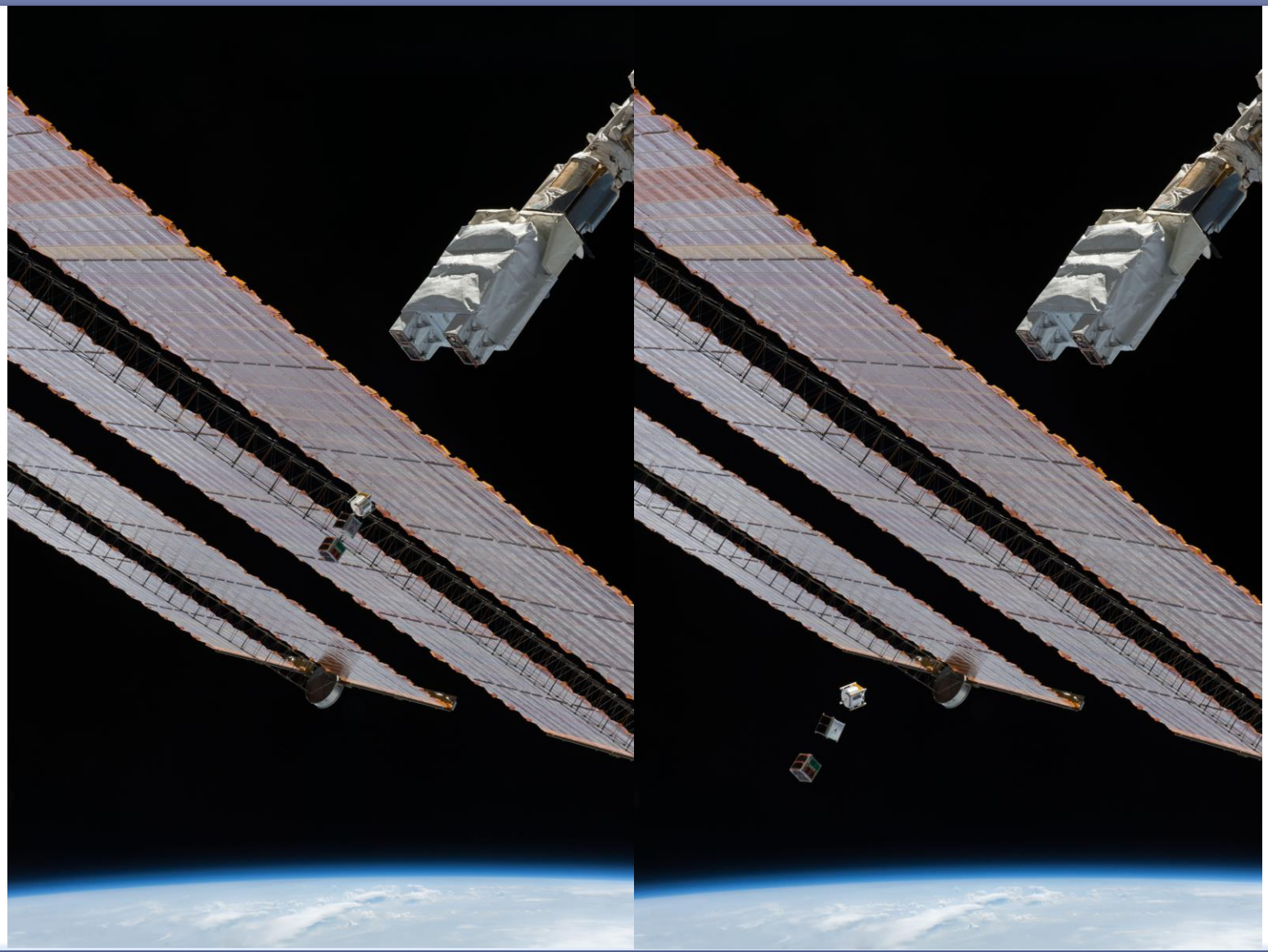
CubeSat Transfer to the ISS © JAXA



Deployment from the ISS © JAXA

# 4. Launch Opportunities for CubeSats

## CubeSat Deployment from the ISS

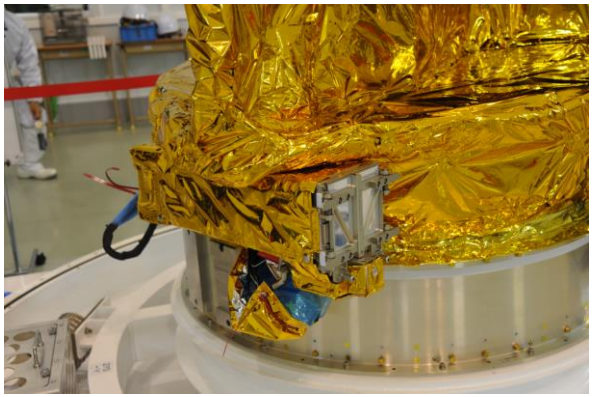


# 4. Launch Opportunities for CubeSats

## Japanese CubeSat Launch Opportunities

- Deployment from the International Space Station (ISS) *KiboCUBE Academy
  - Launch is provided by H-IIB from the Tanegashima Space Center of JAXA
  - CubeSats are delivered to ISS and stored
  - CubeSats are deployed into orbit from the ISS by astronauts / ground control
- Direct launch by rockets
  - H-IIA, Epsilon can provide direct launch into orbit
  - H-IIA will be replaced with the next generation launch vehicle H-III
- Deployment from the HTV-X transfer vehicle

Deployment from the ISS © JAXA



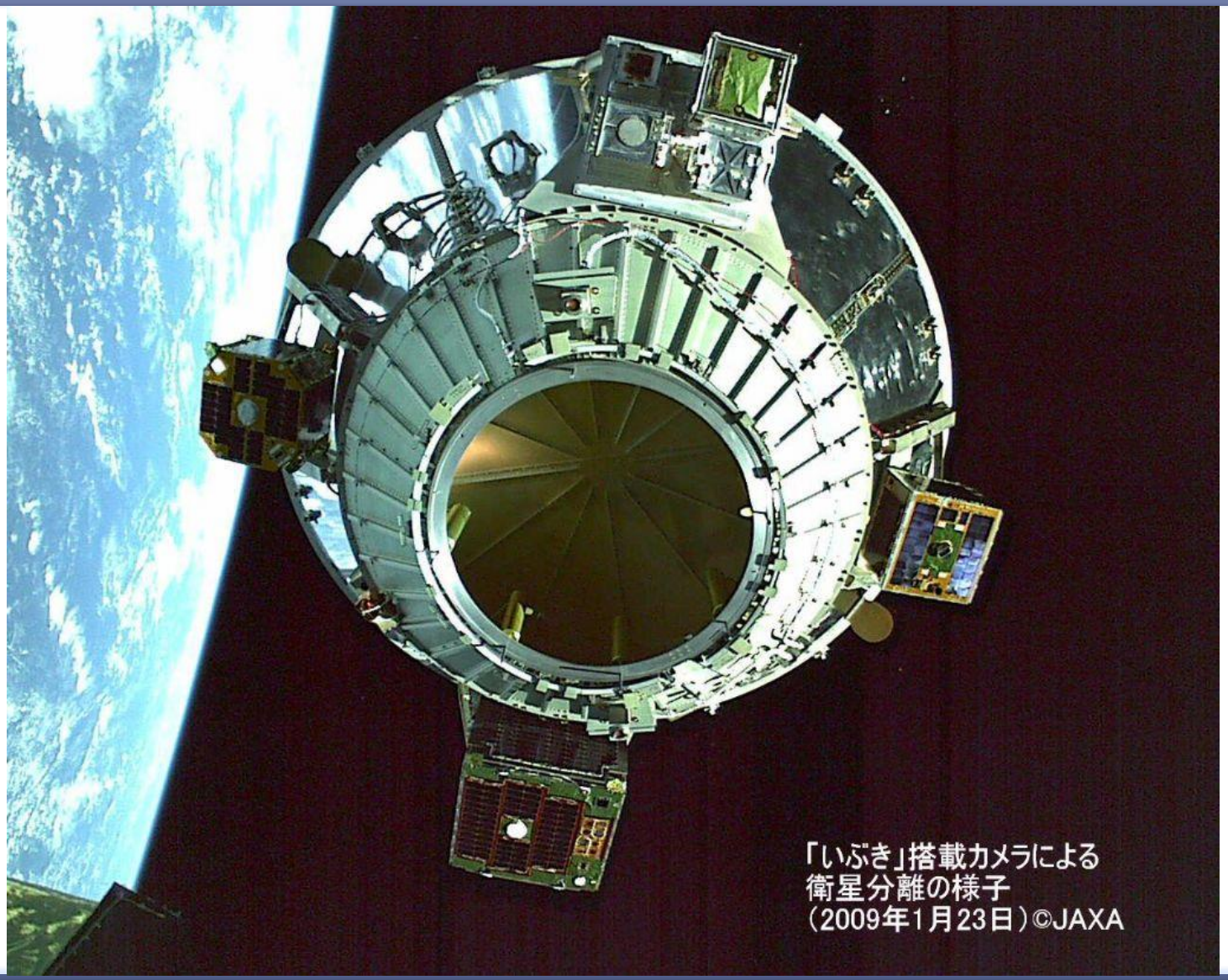
Direct launch (Epsilon Rocket) © JAXA

# 4. Launch Opportunities for CubeSats

## 50-kg-class Micro-satellites Deployment from the ISS

# 4. Launch Opportunities for CubeSats

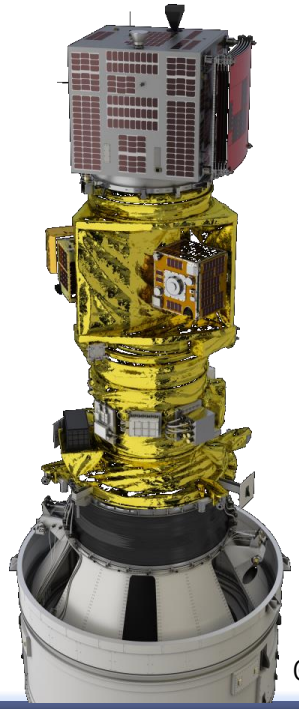
## CubeSats and Micro-Satellites Launch by H-IIA



# 4. Launch Opportunities for CubeSats

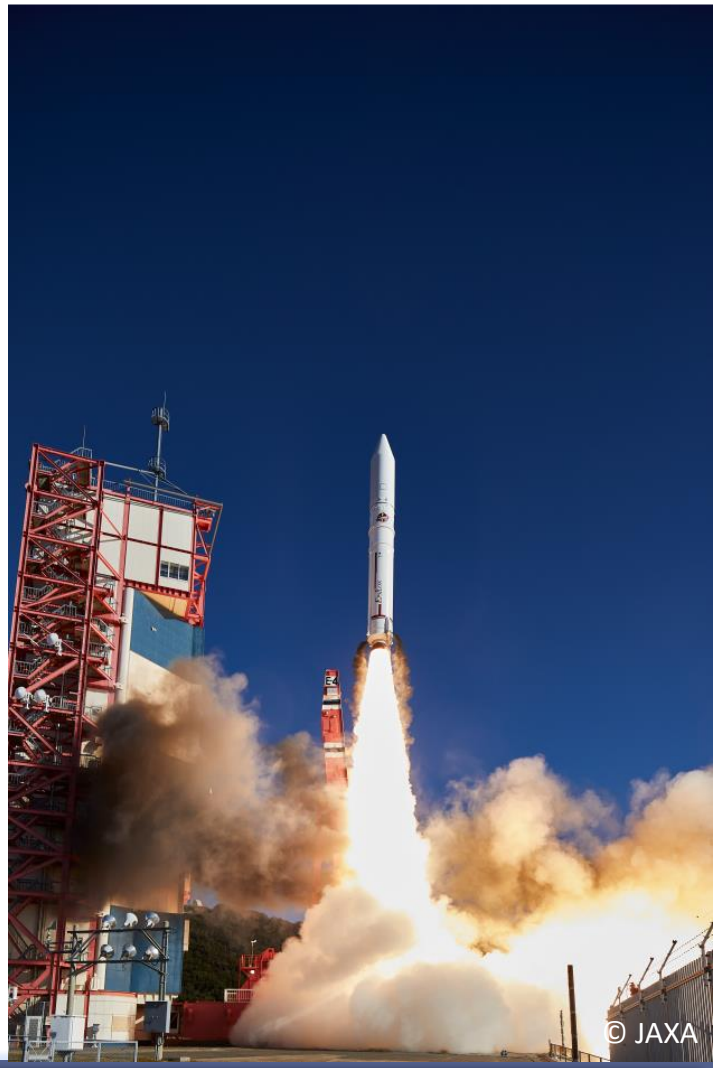
## CubeSats and Micro-Satellites Launch by Epsilon

### JAXA Innovative Satellite Technology Demonstration Program



© JAXA


© JAXA



© JAXA

# 4. Launch Opportunities for CubeSats

## CubeSats and Beyond

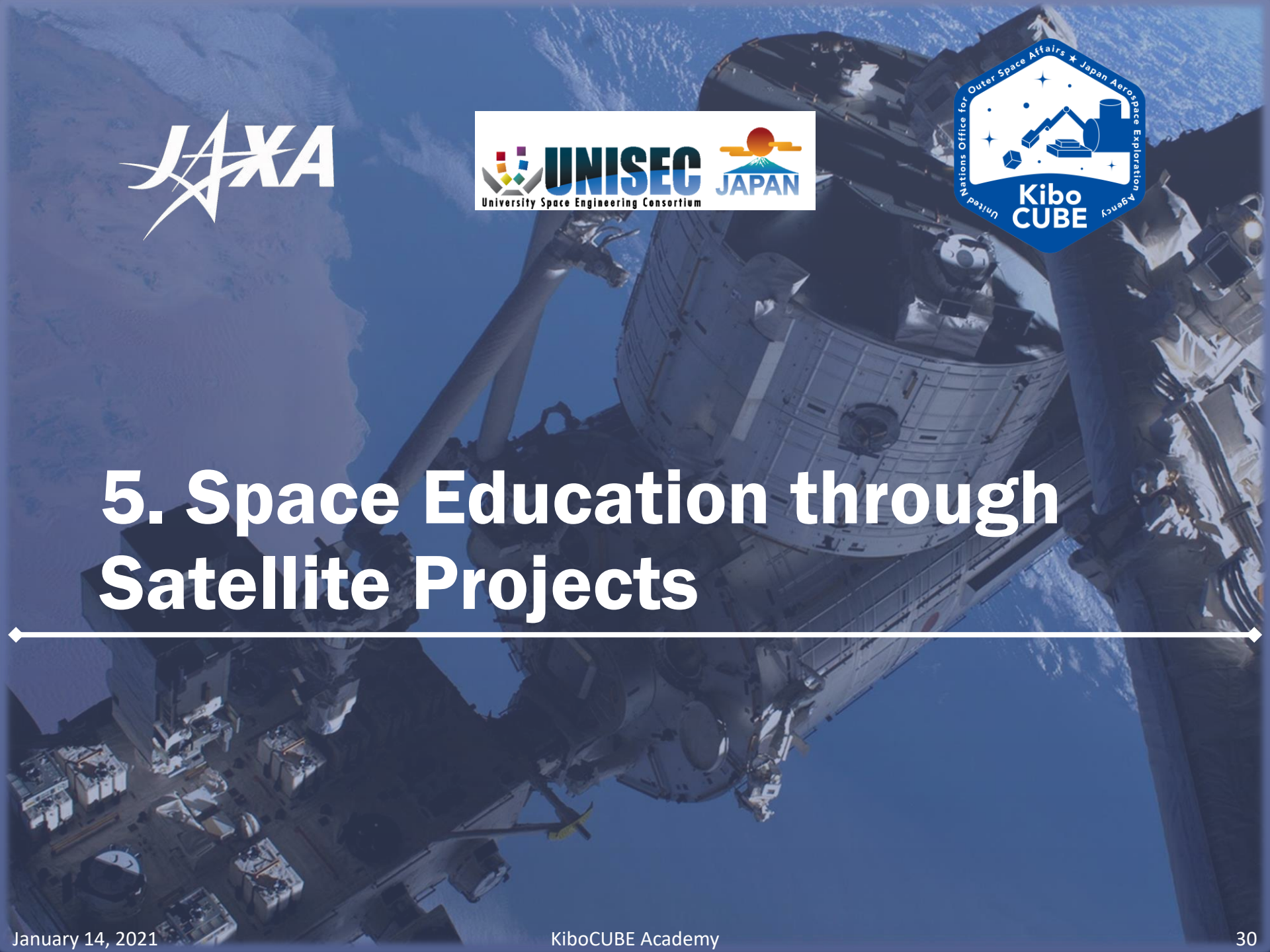
- CubeSats provide the best space education and training opportunities for national capacity building in space development and utilization and open up great possibilities for further advanced space technology development.

- ISS-Kibo also provides advanced space experiment platforms.
  - i-SEEP: IVA-replaceable Small Exposed Experiment Platform
    Space demonstration of electronics, sensors, Earth observation, etc.
  - ExHAM: Experimental Handrail Attachment Mechanism
    Space environment exposure experiments of materials, organisms, etc.

i-SEEP © JAXA

Kibo © JAXA

ExHAM © JAXA



# 5. Space Education through Satellite Projects

# 5. Space Education through Satellite Projects

## Hands-on Space Engineering Education

Space Education through Small Satellite Projects

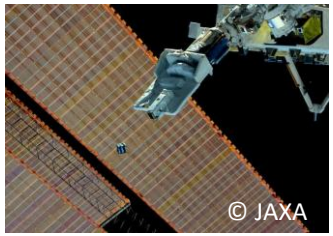
Project members and students experience:

- Mission Analysis
- System Design
- System Development
- Component Procurement
- Component Development
- System Integration
- On-board Software / Algorithm Development
- Ground Verification
- Ground Environmental Test
- Safety Design, Safety Review
- Satellite Delivery and Launch
- Ground Station Installation
- Satellite Operation, Instrument Calibration
- Satellite Data Analysis

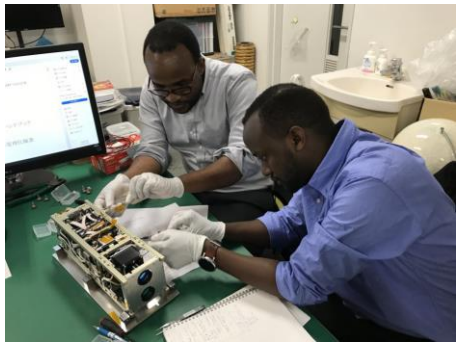
# 5. Space Education through Satellite Projects

## International Space Engineering Education Opportunities

- KiboCUBE
  - JAXA/UNOOSA program
  - Provide opportunities for educational and research institutions from developing countries with United Nations membership
- BIRDS Program
  - Kyushu Institute of Technology (Kyutech)
  - CubeSat development, hands-on training, education, academic program.
- RWASAT-1
  - University of Tokyo
  - CubeSat development, hands-on training, education.
- Micro-Satellite Program
  - Tohoku University and Hokkaido University
  - 50-kg-class Earth observation micro-satellite projects
  - Hands-on activities, education, academic program.
  - Establishment of Asia Micro-satellite Consortium (AMC)
- JAXA and Japanese Universities have strong collaborative relationships.







© University of Tokyo/Arkedge Space/RURA

# 5. Space Education through Satellite Projects

## DIWATA-1 (Philippine Micro-satellite)

# 5. Space Education through Satellite Projects

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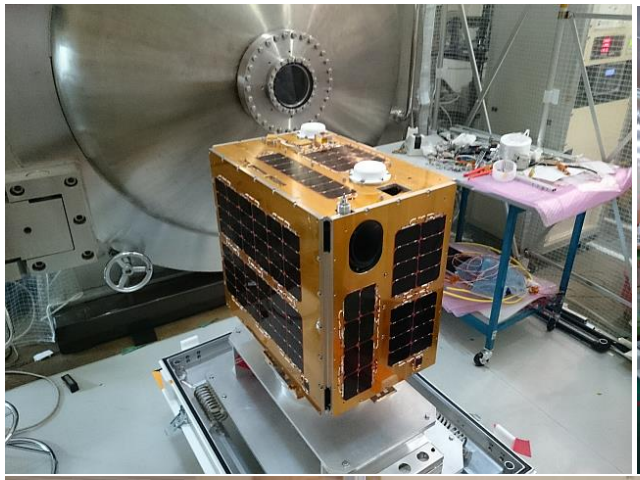
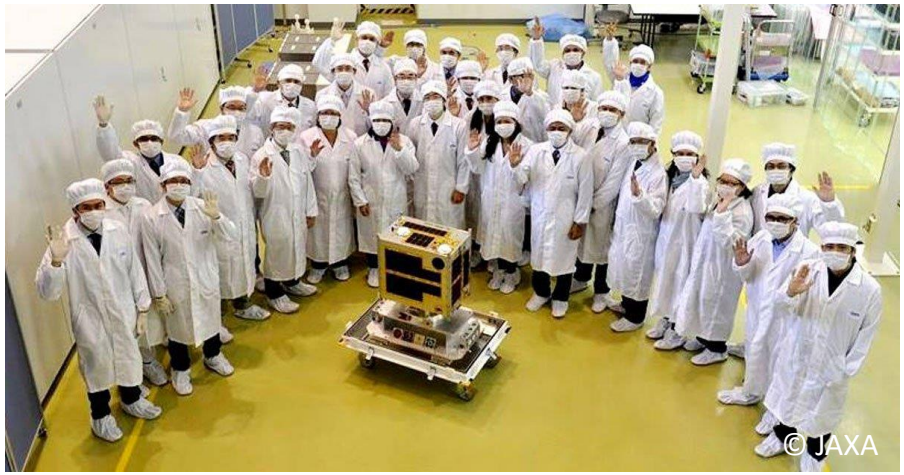
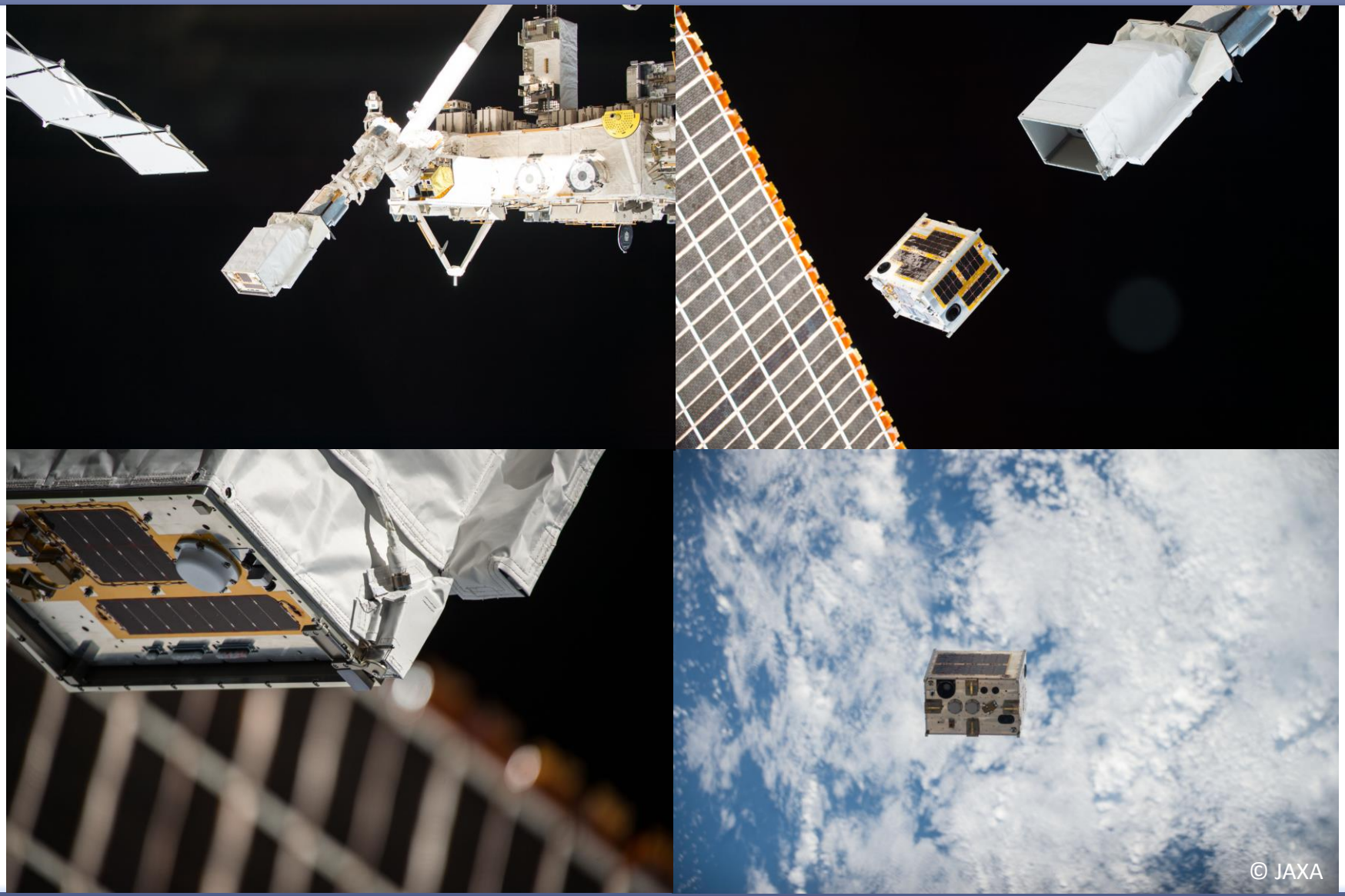




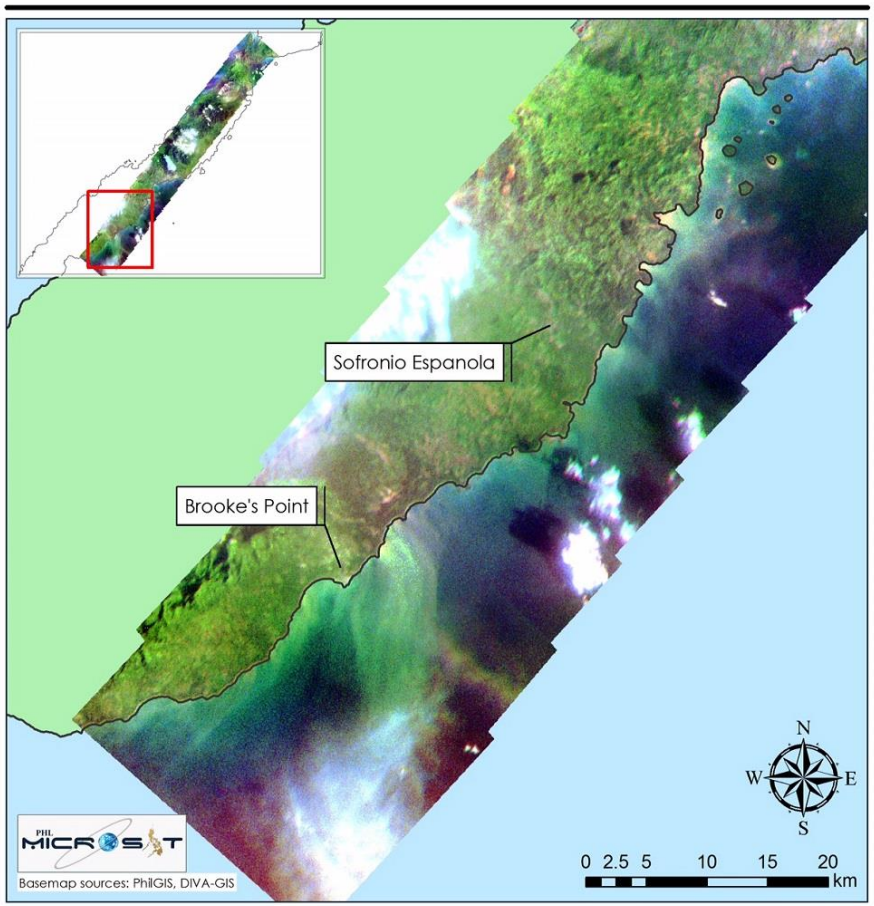

# 5. Space Education through Satellite Projects

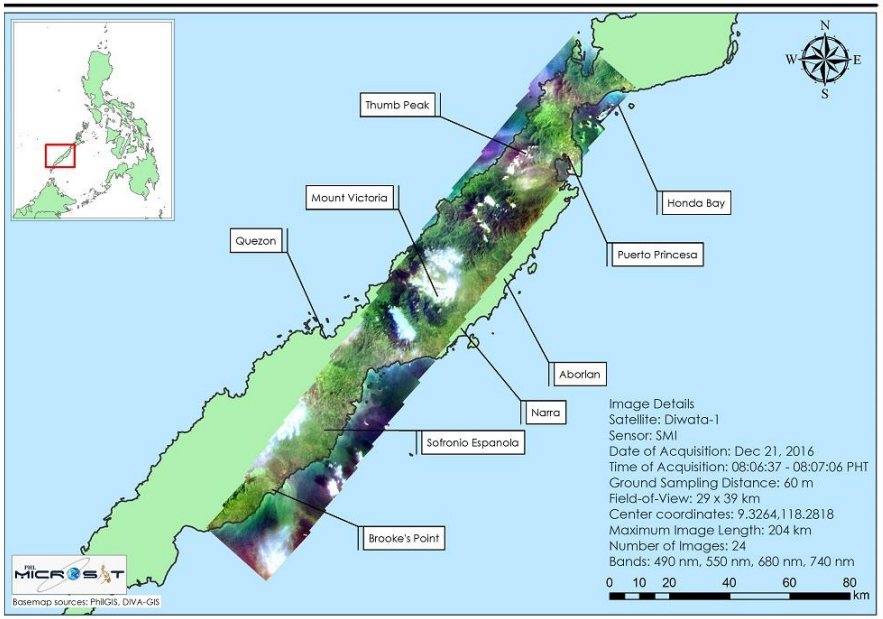
## DIWATA-1 (Philippine Micro-satellite)

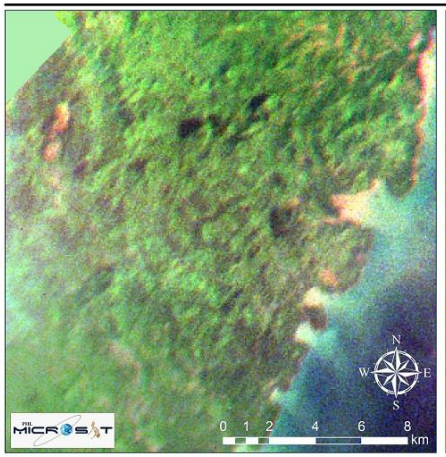


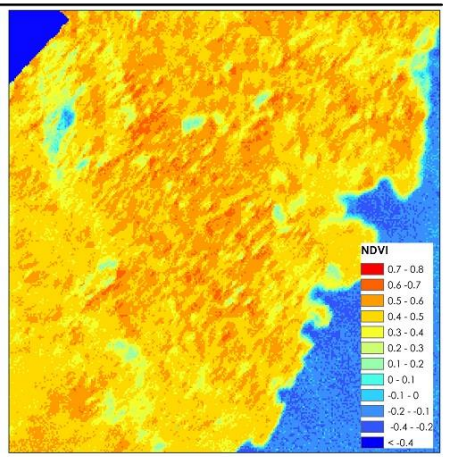
# 5. Space Education through Satellite Projects

## DIWATA-1 Multi-spectral Images




*Space-borne Multi-spectral Imager (SMI)*
*Palawan, Philippines - Dec. 21, 2016*

*http://newsbytes.ph/2017/03/06/photos-diwata-1-micro-satellite-captures-images-of-silted-palawan-areas/*

# 5. Space Education through Satellite Projects

## UNISEC Space Engineering Education Activities

### University Space Engineering Consortium


*No one will be left behind!*

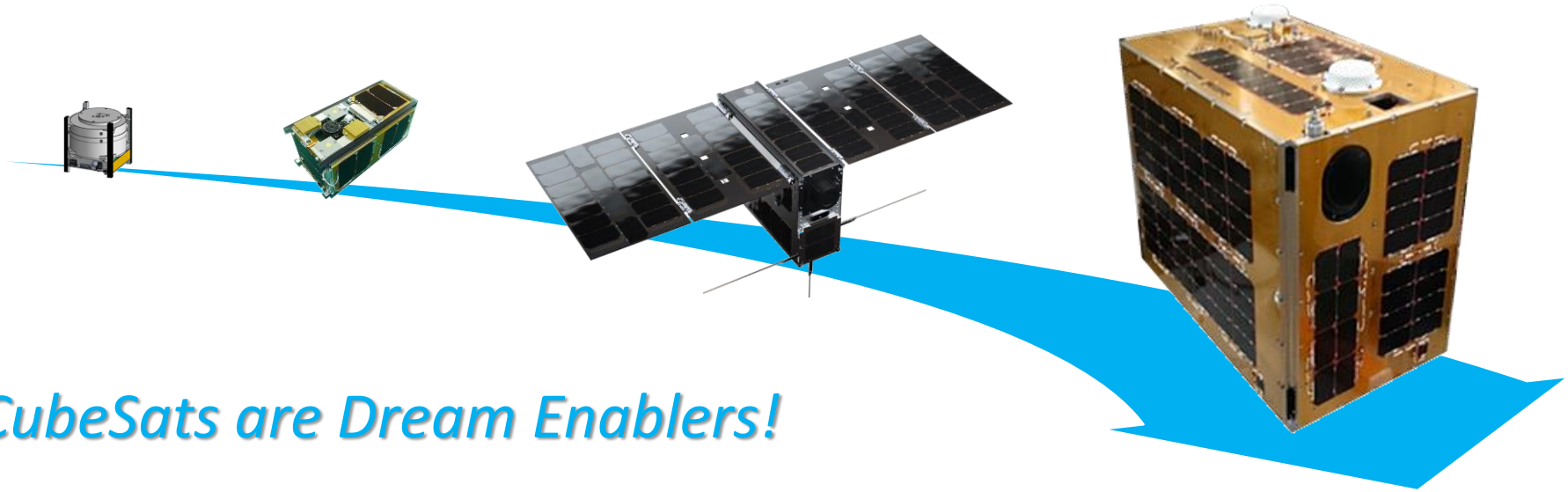
# 6. CubeSats are Dream Enablers

# 6. CubeSats are Dream Enablers

## Stepwise Development of CubeSats and Beyond

*"Start small, go big!"*

- Recently, CubeSats have become a major game-changer in the world.
- Thanks to the technology advancement of small satellites, CubeSats are no longer for education only, but for actual space development and utilization.
- Achievements obtained from smaller CubeSats can be directly applied to larger satellites for even more advanced missions.
- 1U CubeSats bring everything within your reach!



***CubeSats are Dream Enablers!***

# 6. CubeSats are Dream Enablers

## Worldwide CubeSat Community

- Thanks to the standardized specifications and interfaces of CubeSats, educational and research institutions can share their experiences, engineering skills, on-board components, software, launch opportunities and even the missions
- By benefitting from each other in the worldwide CubeSat community, one can rely on some of the already established technologies and can realize quick and secure access to space.
- CubeSats can be enabling tools for future space exploration for new engineering and scientific findings, affecting many areas of life on Earth.
- CubeSats can also be one of the future business markets for the nations involved.

# 7. Conclusion

# 7. Conclusion

- Small satellites, especially CubeSats, are now changing the game of space development and utilization through their low-cost rapid development characteristics, which are based on standardized specifications and interfaces.
- CubeSats are the best platform for getting started with space development and utilization, and KiboCUBE Academy facilitates access to space for becoming spacefaring nations.
- Through CubeSat projects, nations can build up national capacity in spacecraft engineering, design and construction, and operation, which opens up doors for even more challenging space activities for fostering innovation and technological advancement.


# Thank you very much.