KiboCUBE Academy

Lecture 01 – Second Edition

Introduction to Small Satellite Mission and Utilization

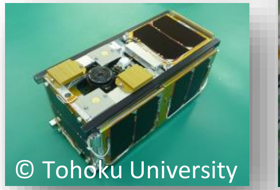
Tohoku University

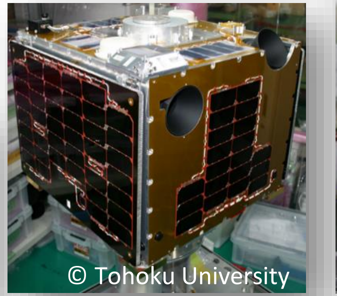
Department of Aerospace Engineering

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

Lecturer Introduction





Toshinori Kuwahara, Dr. –Ing.

Position:

2015 - Associate Professor, Department of Aerospace Engineering, Tohoku University
2017 - Technical Advisor, Nakashimada Engineering Works, Ltd.
2017 - Technical Advisor, ALE Co., Ltd.
2020 - Chairperson, University Space Engineering Consortium Japan (UNISEC)
2021 - Co-founder/CTO, ElevationSpace Inc.

Research Topics:
Space Development, Utilization, and Exploration by Small Spacecraft Technologies

Contents

1. Introduction to Space Technologies and Utilization

1.1. 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

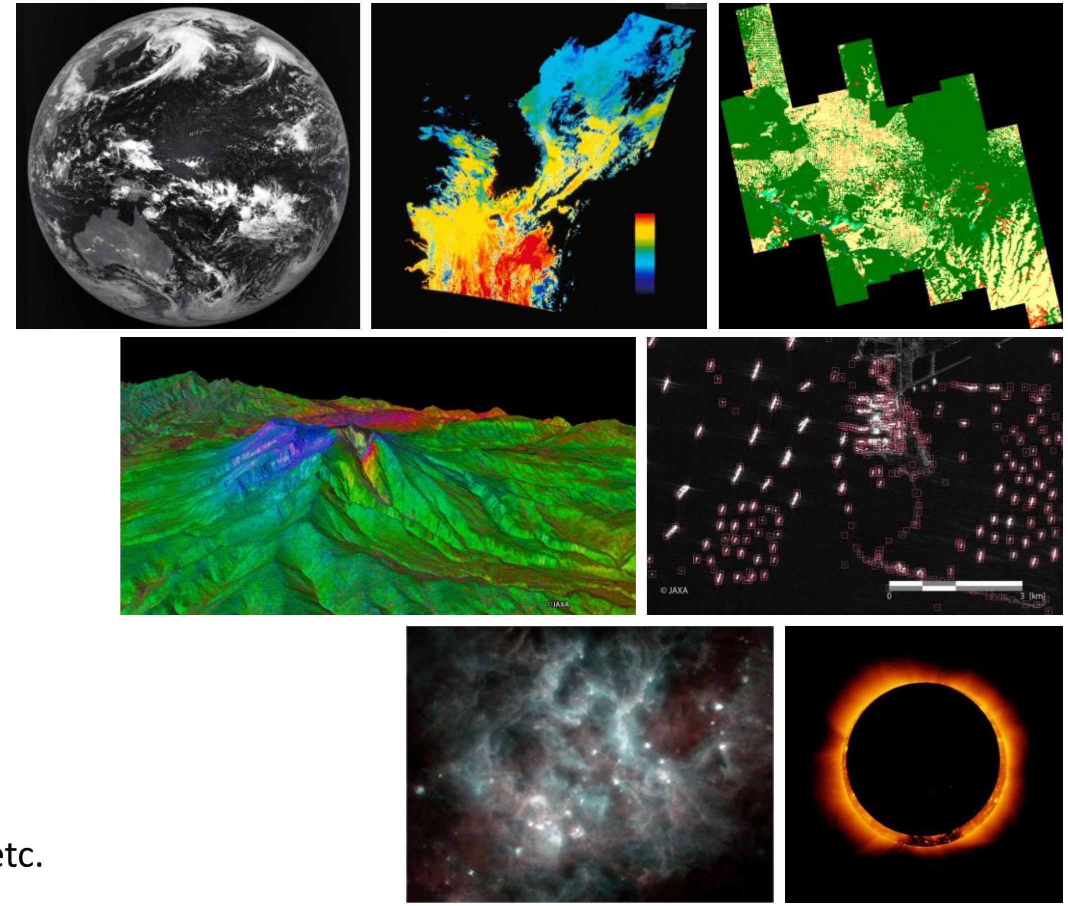
KiboCUBE Launch, Delivery to the ISS, and Deployment from the ISS © JAXA

1. Introduction to Space Technologies and Utilization

1.2. Satellite Applications

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

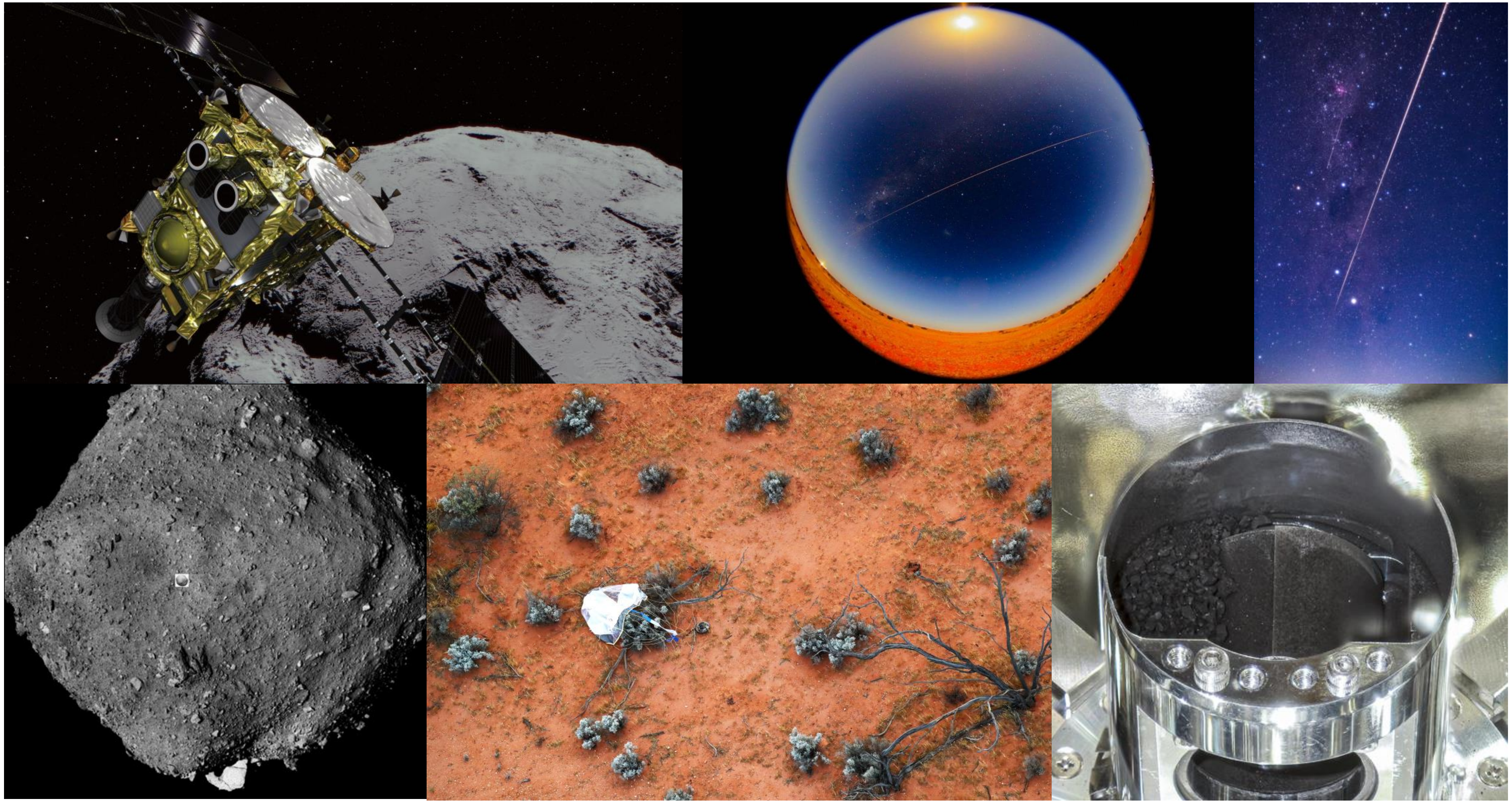
- **Earth Observation**
  - Meteorological Observation
  - Oceanographical Observation
  - Geographical Observation
  - Coastal Area Observation
  - Atmospheric Observation
  - Disaster Monitoring and Prevention
- **Communication**
  - Satellite Broadcasting
  - Telephone, Internet, etc.
- **Navigation**
  - 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.



1. Introduction to Space Technologies and Utilization

1.3. Space Exploration

- Asteroid Sample Return Mission – *Hayabusa-2*

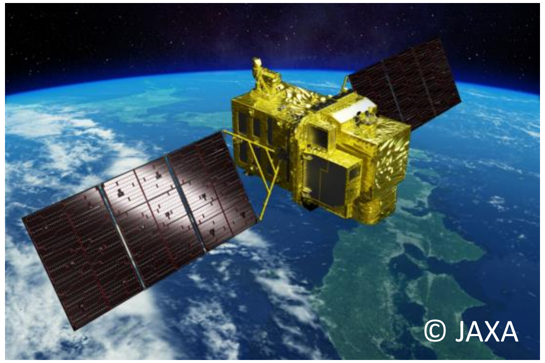


2. Emerging Technologies of Small Space Systems

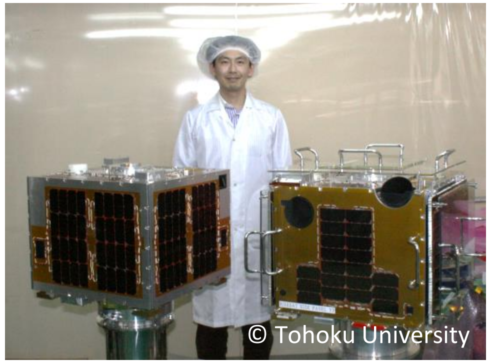
2.1. Characteristics of Small Space Systems

Comparison between large and small satellites:

Large Satellite



Small Satellite



Large	Mass	**Small**
High	Cost	**Low**
Long	Development Time	**Short**

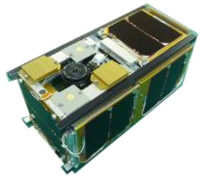
- Dedicated launch
- Need high-reliability, low-risk
- High-performance,
Low observation frequency

- 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

2.2. Mass Categories

Small, Micro, Nano, and Pico-satellites.

CubeSat



© ALE

© IRS, University of Stuttgart

Pico-Satellite | Nano-Satellite | Micro-Satellite | Small/Medium Satellite

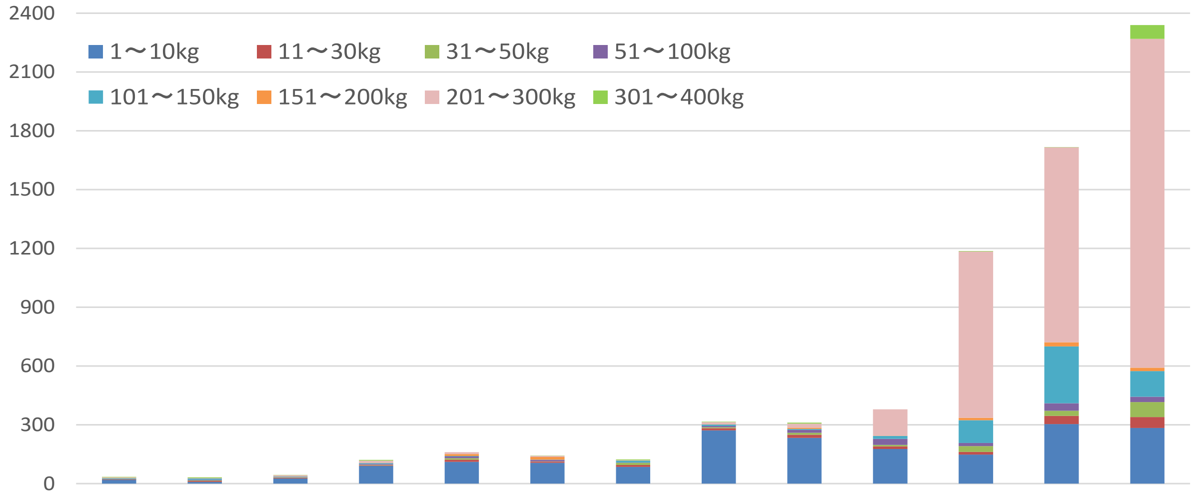
0kg | 1kg | 10kg | 100kg | 1000kg

2.3. Accelerating Utilization of Small Space Systems

- The number of small satellites smaller than 400kg, including mega-constellations, is rapidly increasing.

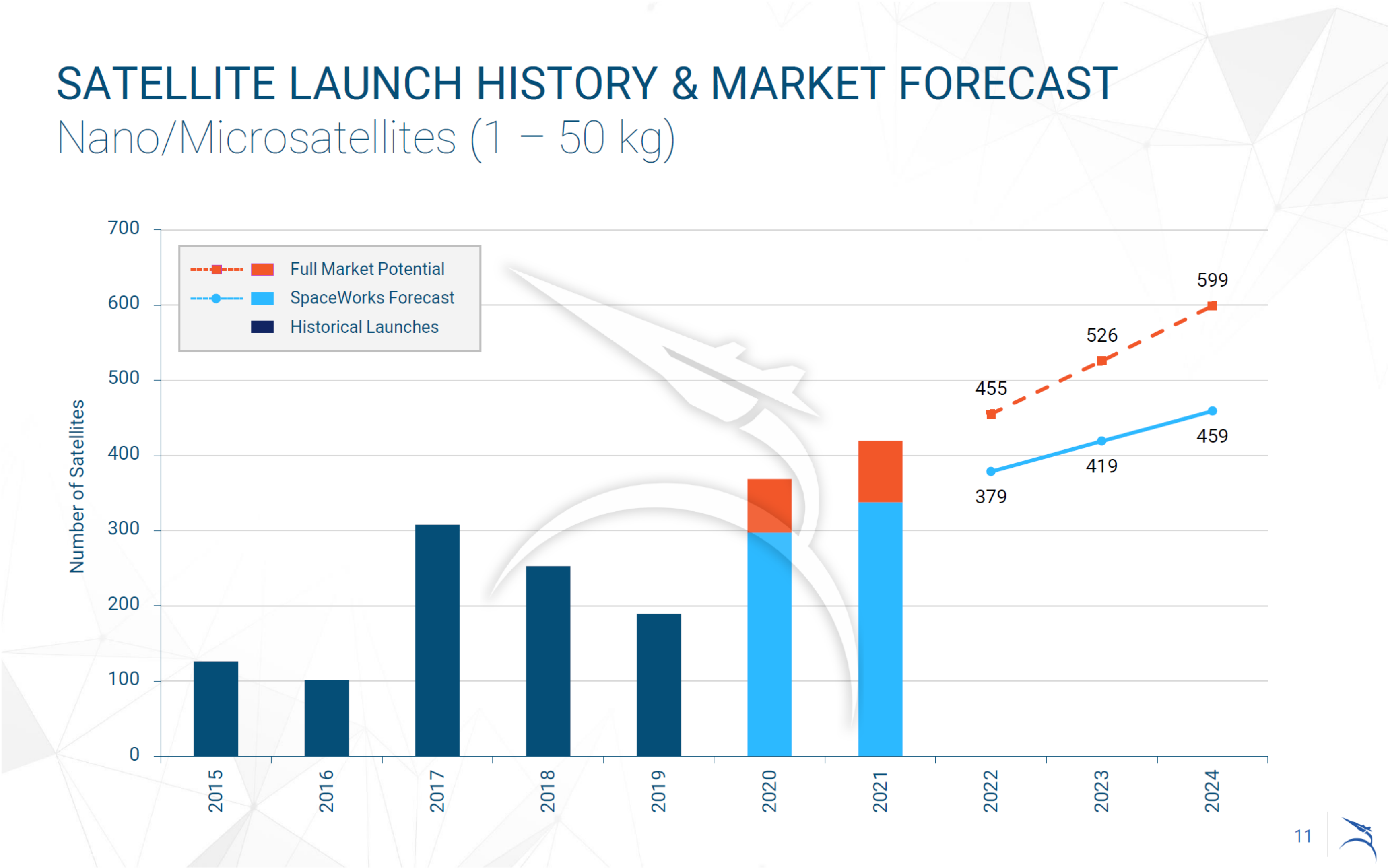
Launches of Small Satellites (1~400kg)

(Successful Launches Only)



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1～10kg	19	9	26	90	112	106	85	272	234	177	149	304	284
11～30kg	2	5	4	4	10	7	10	11	16	13	13	42	56
31～50kg	1	2	3	3	8	1	11	5	10	8	30	26	76
51～100kg	1	4	2	4	9	7	2	6	14	31	16	38	28
101～150kg	4	6	2	4	2	2	10	8	6	14	116	291	131
151～200kg	2	1	2	2	10	13	1	1	5	2	12	21	17
201～300kg	4	2	4	11	10	6	1	11	21	135	848	994	1678
301～400kg	2	3	2	3	0	1	4	2	5	0	3	1	70
Total	35	32	45	121	161	143	124	316	311	380	1187	1717	2340

2.4. Launches of Micro-Satellites and CubeSats



2. Emerging Technologies of Small Space Systems

2.5. 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

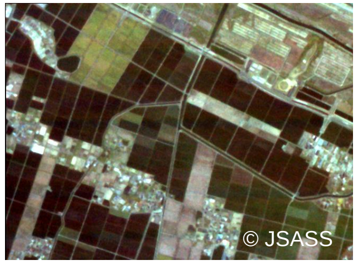
- Internet communication
- M2M (Machine-to-Machine) communication
- AIS (Automatic Identification System)
- High-speed laser communication

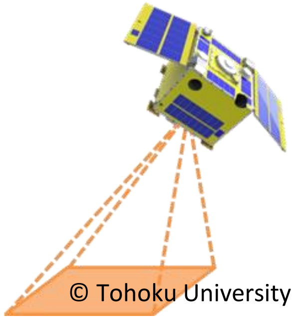
New technologies

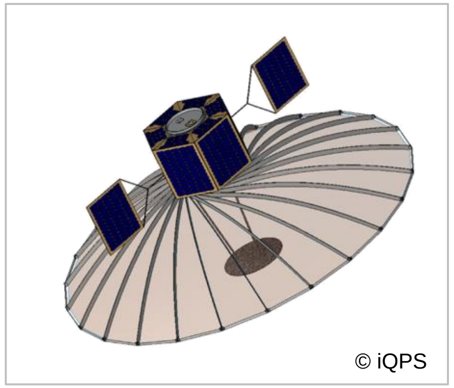
- Debris removal
- Re-entry and return capsule
- On-orbit servicing
- Artificial shooting stars

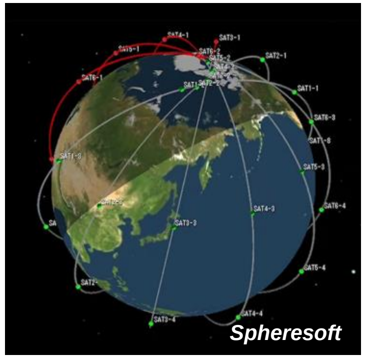
Science

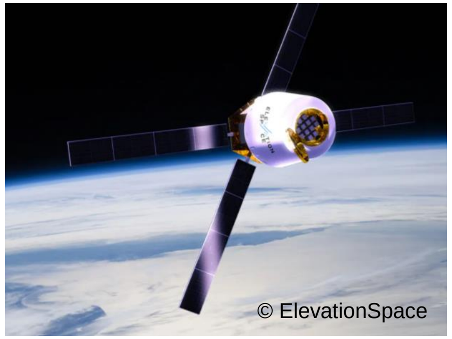
- Astronomical, Space weather
- Moon, Asteroids, Planets, and Deep Space Exploration.

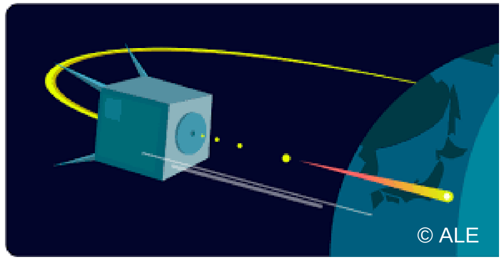


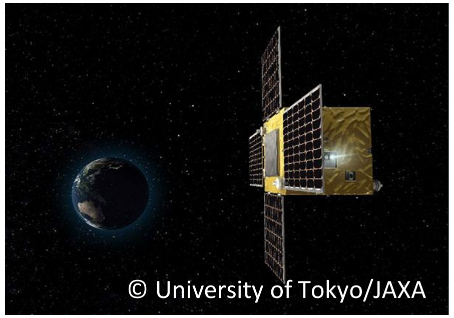






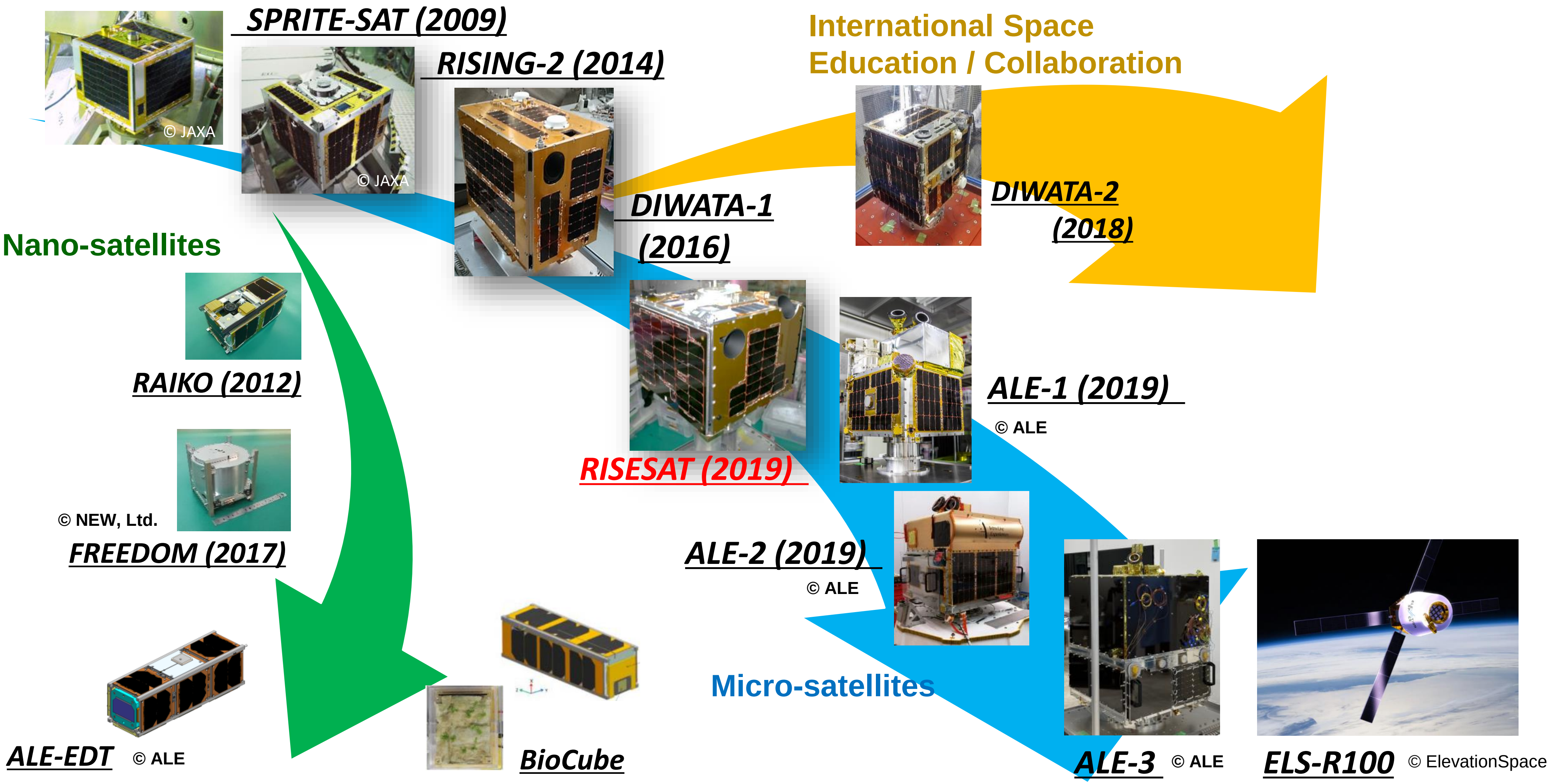






2. Emerging Technologies of Small Space Systems

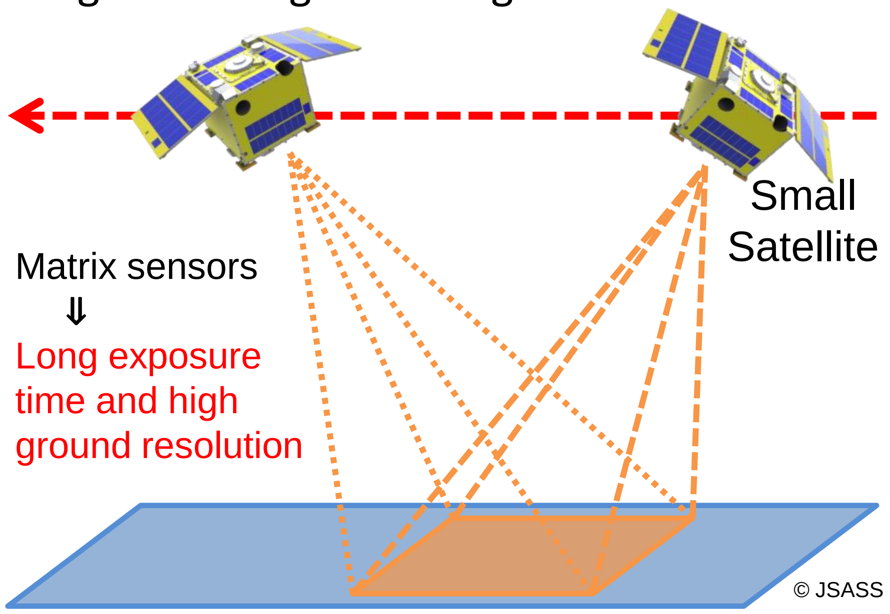
2.6. Exemplary Small Satellite Projects at Tohoku University



2.7. Earth Observation – Micro-satellite RISESAT Example

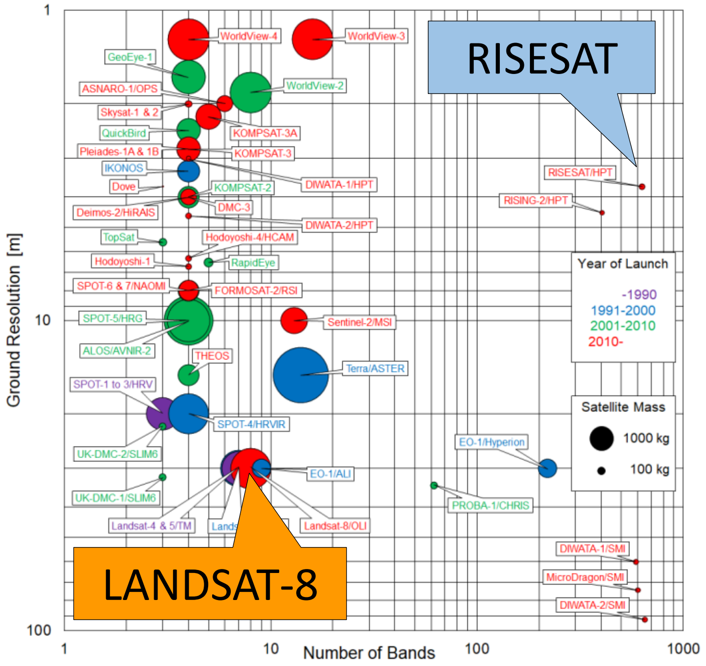
- Demonstration of high-resolution multi-spectral Earth observation.
    - Cassegrain Telescope with 3.7 m ground sampling distance.
    - Liquid crystal tunable filters (LCTF) (420-650nm, 650-1050nm = 630 bands)
- Combined with high-accuracy target pointing attitude control.

Target Pointing：Active agile attitude control



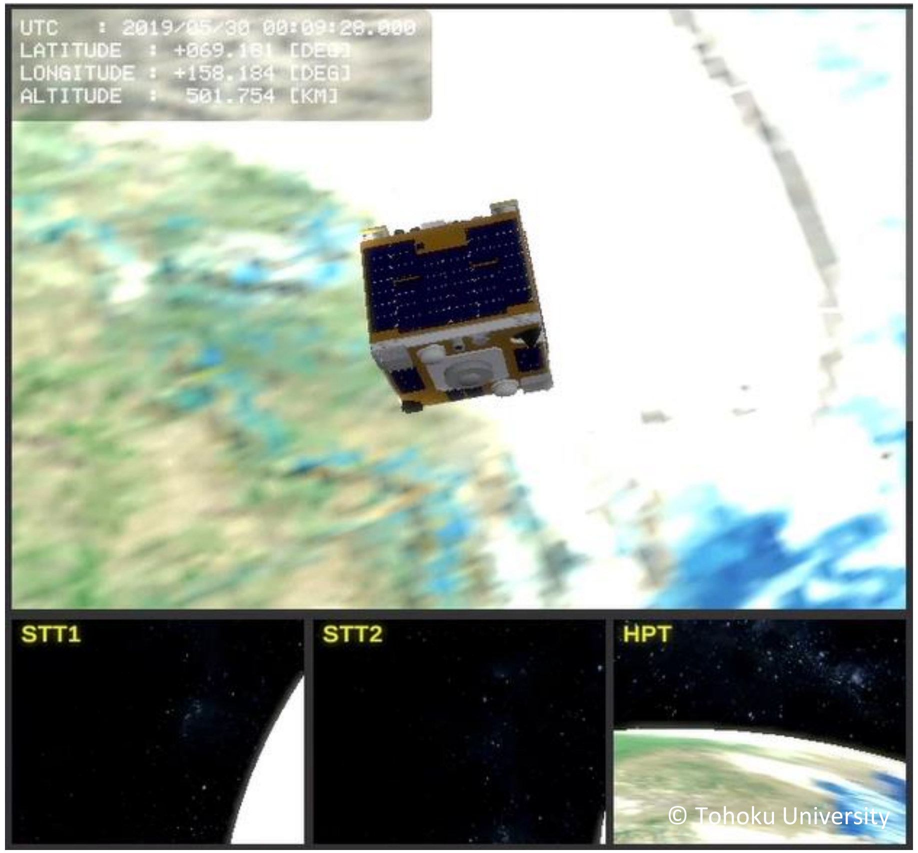
High-resolution, multi-spectral observation.

GSD –Number of Bands



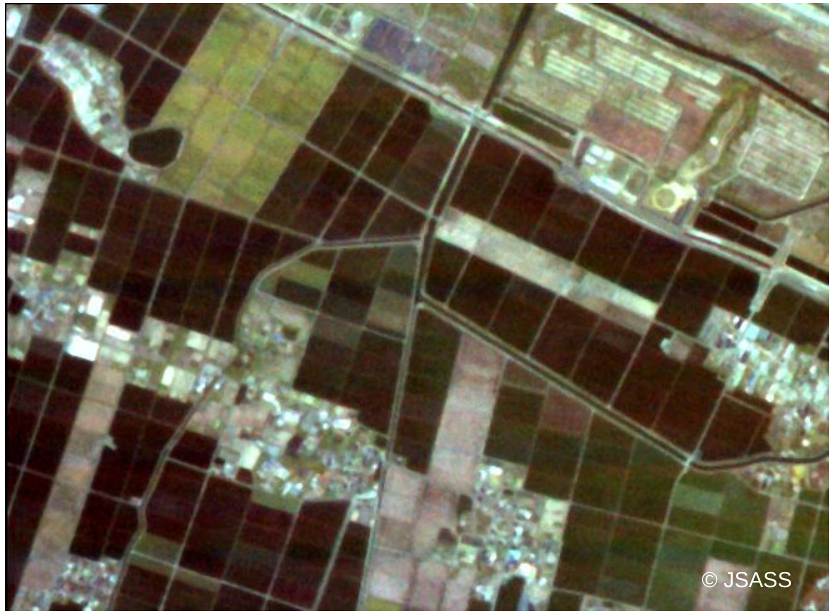
J. Kurihara, et al, *sensors*, 18, 619, (2018), pp.1-11

2.7. Earth Observation – Micro-satellite RISESAT Example



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

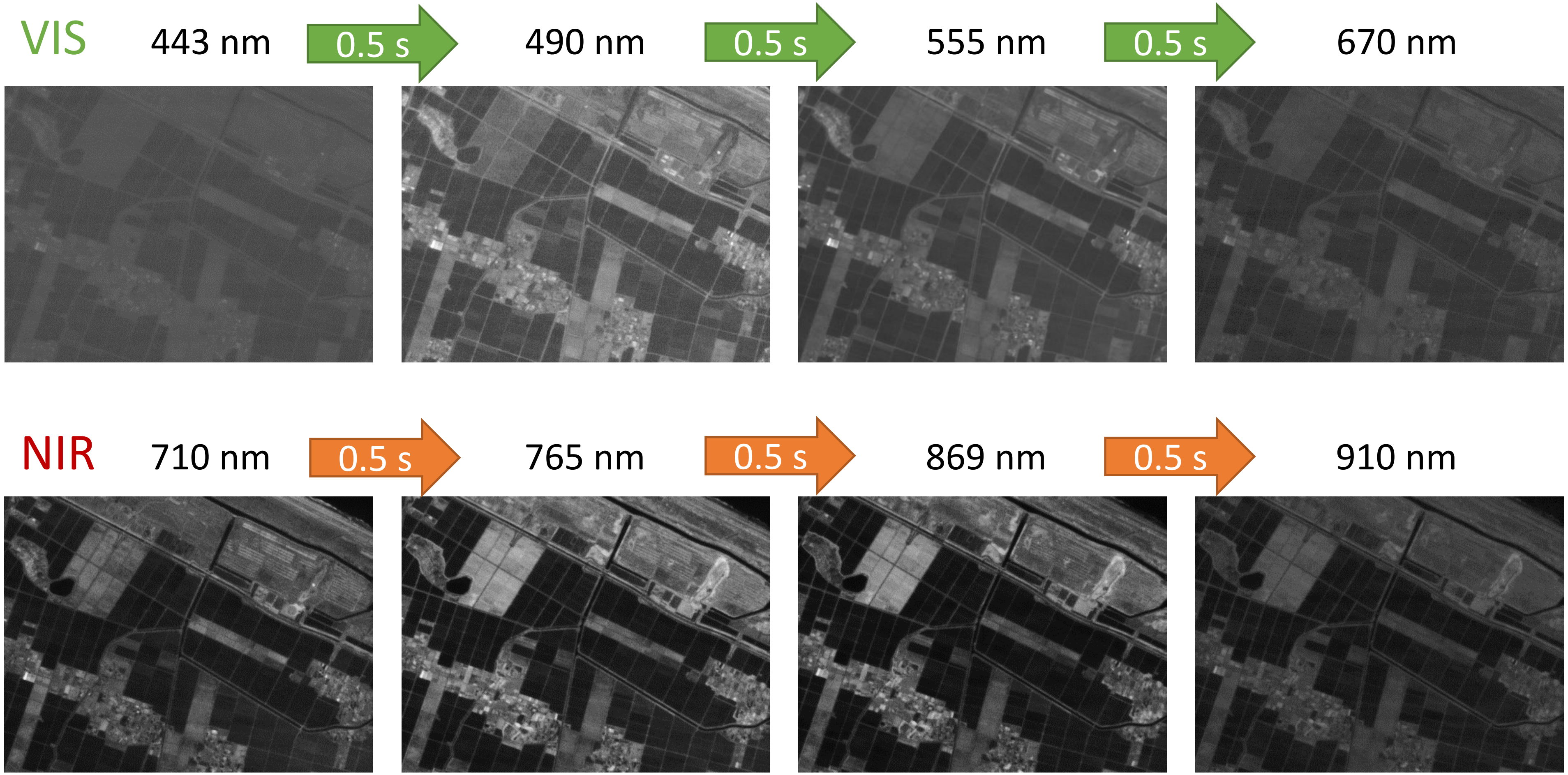
- Generated from the actual downlinked log data of attitude determination and control.
- x 50 speed



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

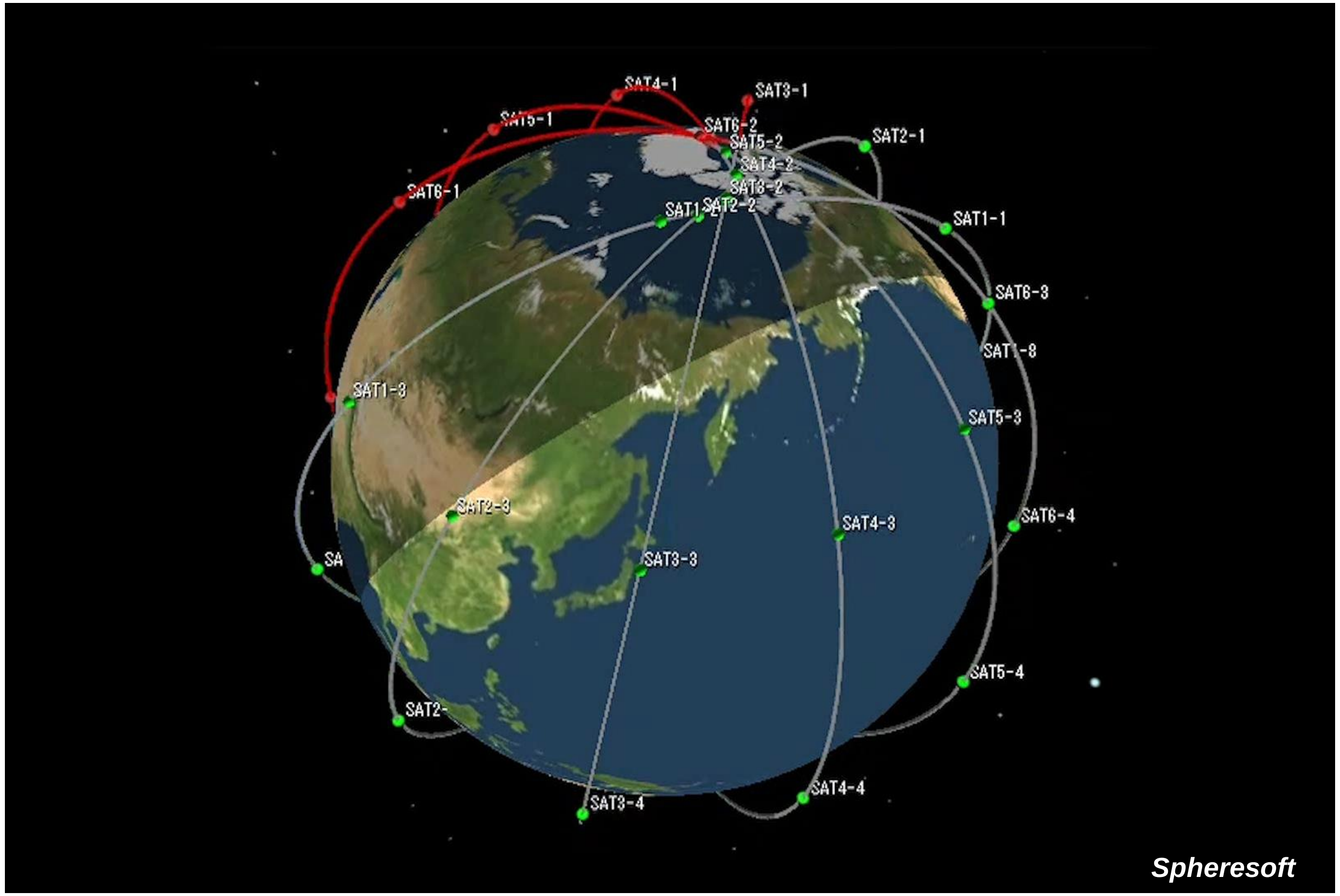
2.7. Earth Observation – Micro-satellite RISESAT Example

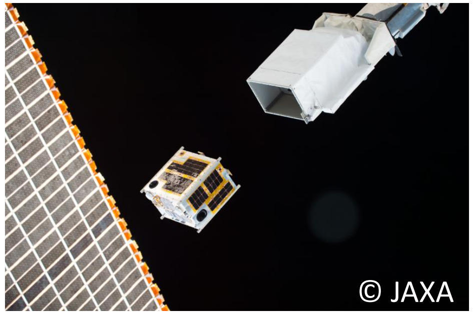


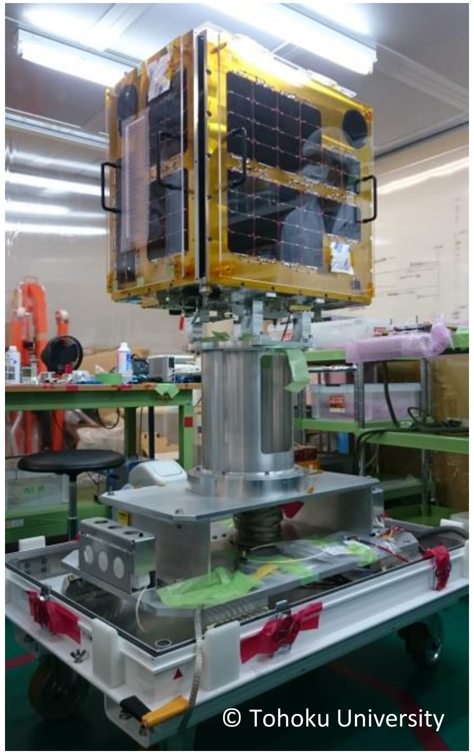
J. Kurihara, et al, *Trans. JSASS Aerospace Tech. Japan*, Vol. 18, No. 5, pp. 186-191, 2020.

2.8. Small Satellite Constellation

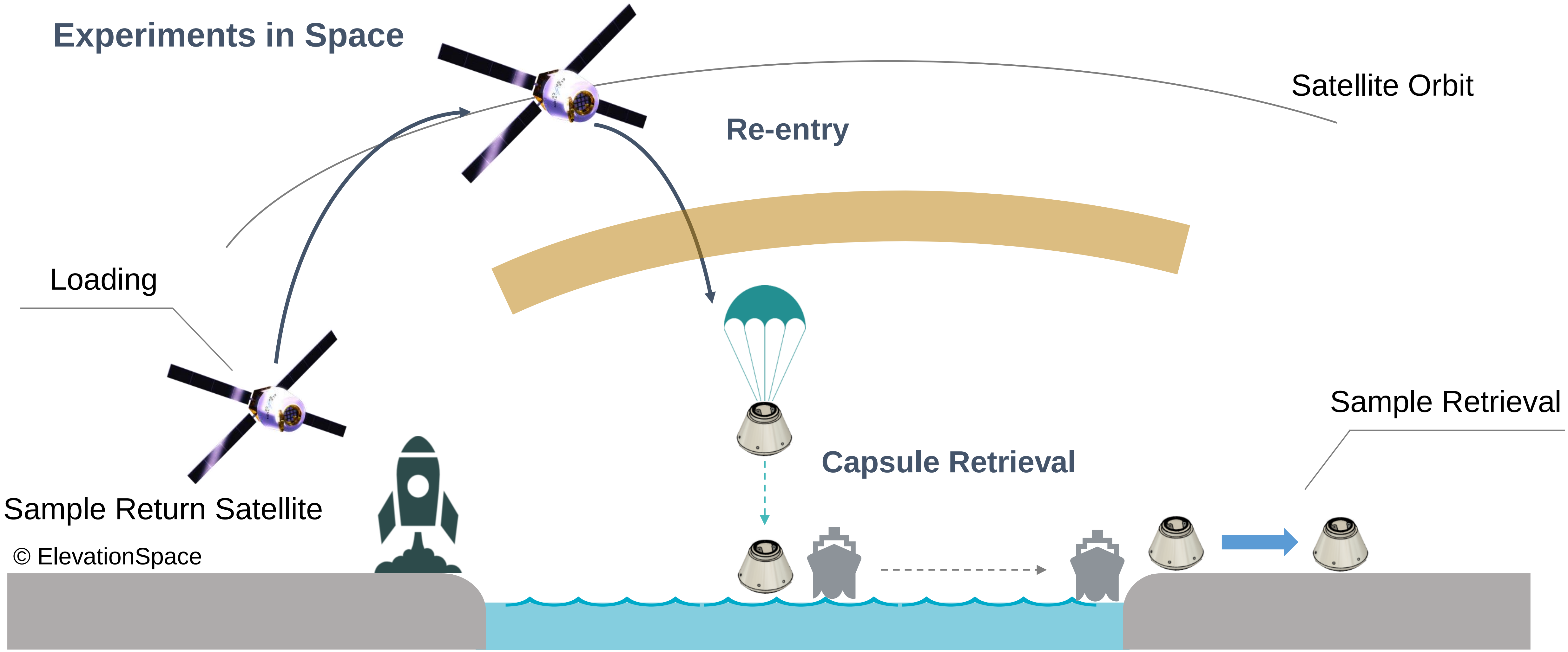
- Thanks to the characteristics of small satellites, they can be operated in a constellation to achieve higher revisit frequencies all over the world.







2.9. Sample Return with Re-entry Capsule

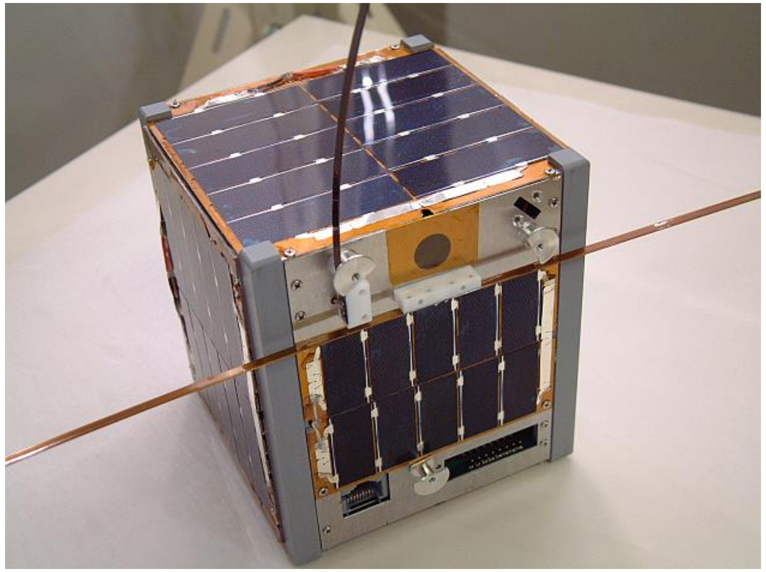


3. Characteristics and Capabilities of CubeSats

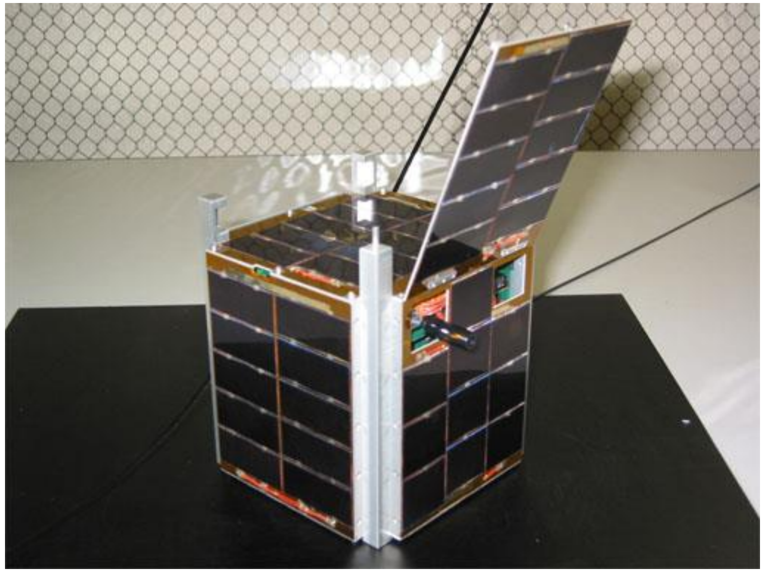
3. Characteristics and Capabilities of CubeSat

3.1. 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.



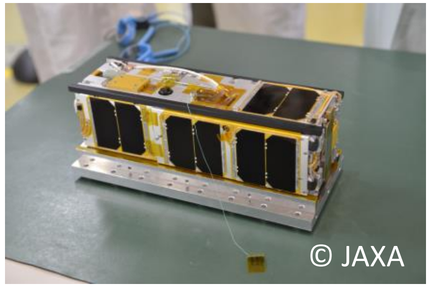
XI-IV © University of Tokyo



CUTE-I © Tokyo Institute of Technology

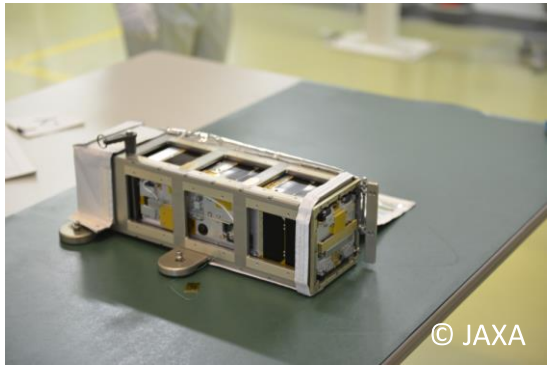
3.2. Types of CubeSats

- 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.



© JAXA

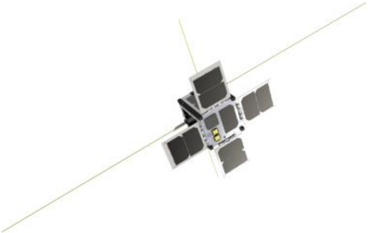
3U CubeSat

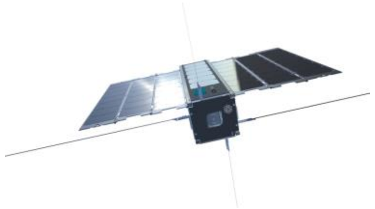


© JAXA

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.





3. Characteristics and Capabilities of CubeSat

3.3. 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

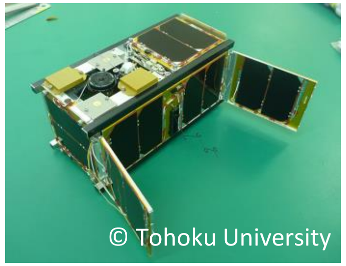
- Data relay
- M2M (Machine-to-Machine) communication
- AIS (Automatic Identification System)
- High-speed laser communication

New technologies

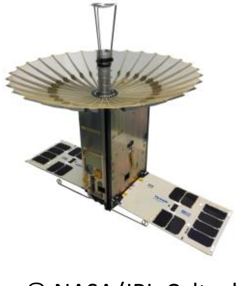
- GNSS signal occultation measurement
- Space robotics
- Electrodynamic Tether
- Re-entry and return capsule

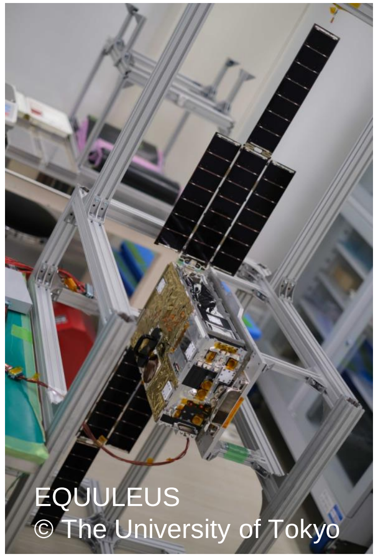
Science

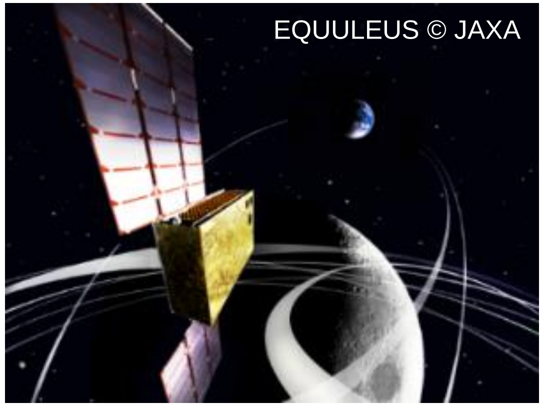
- Astronomy
- Bioscience experiment
- Moon, Asteroids, Planets, and Deep Space Exploration.

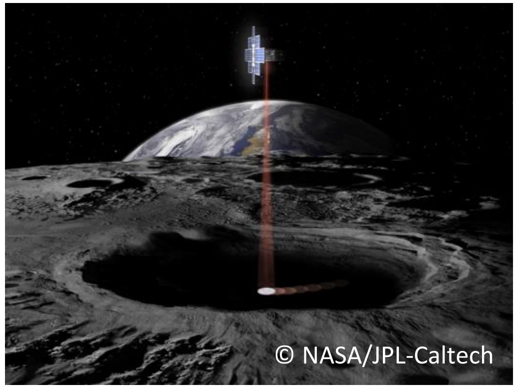

© Tohoku University

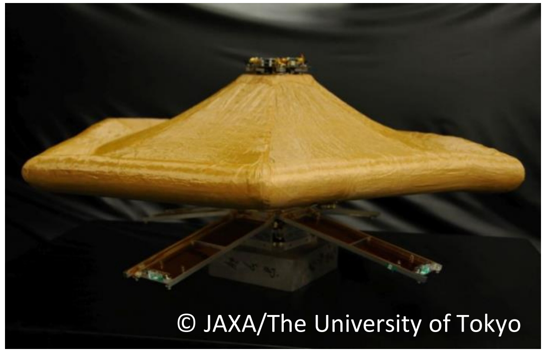

© NASA/JPL-Caltech

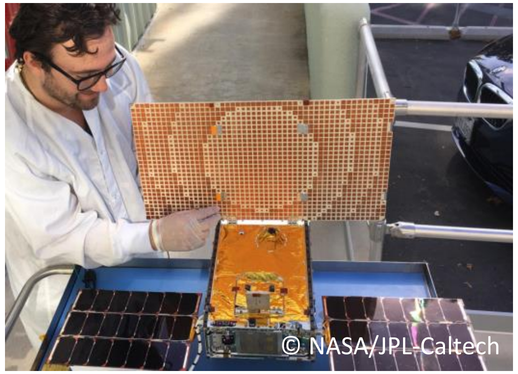

© NASA/JPL-Caltech


EQUULEUS
© The University of Tokyo

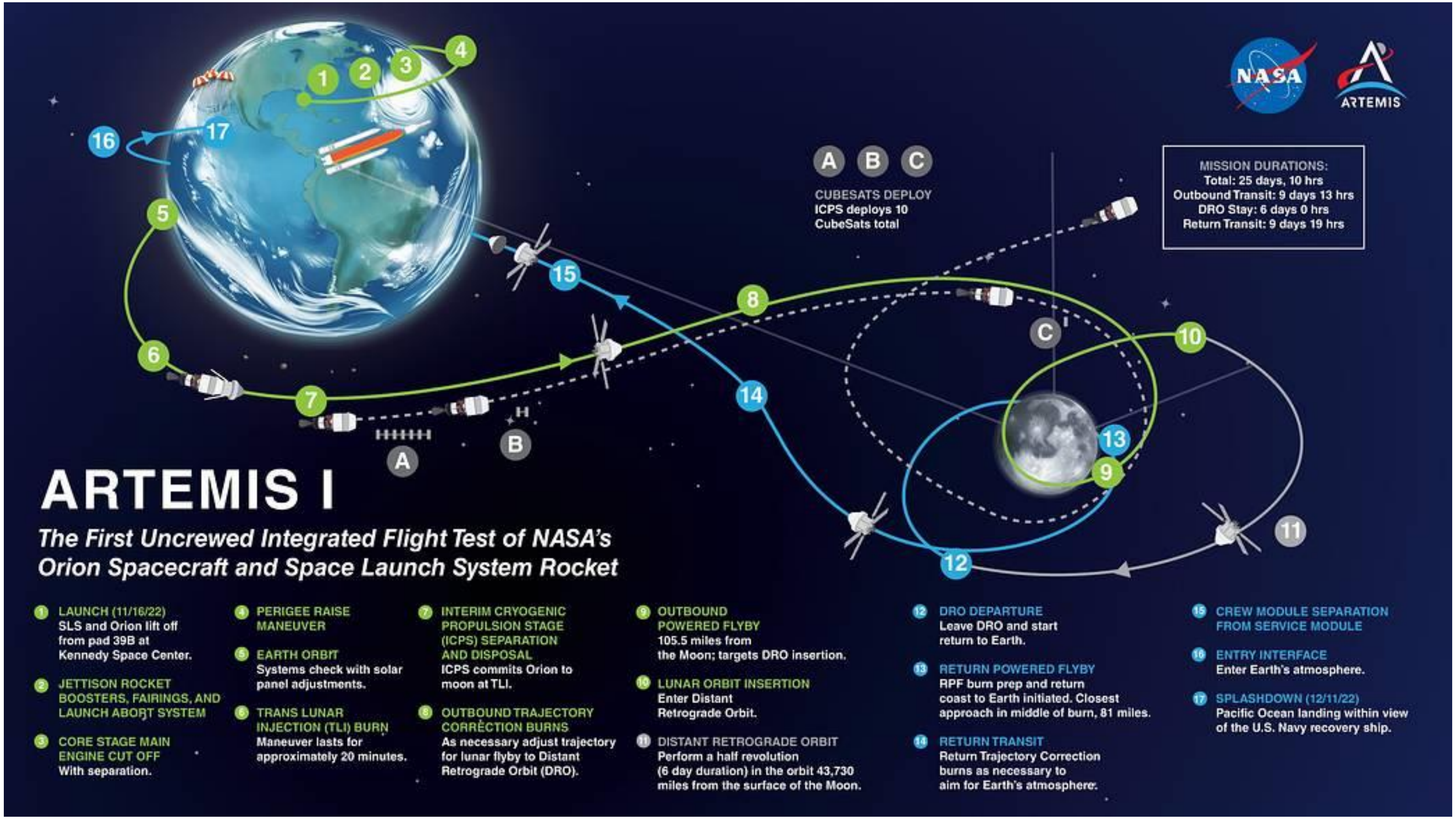

EQUULEUS © JAXA


© NASA/JPL-Caltech

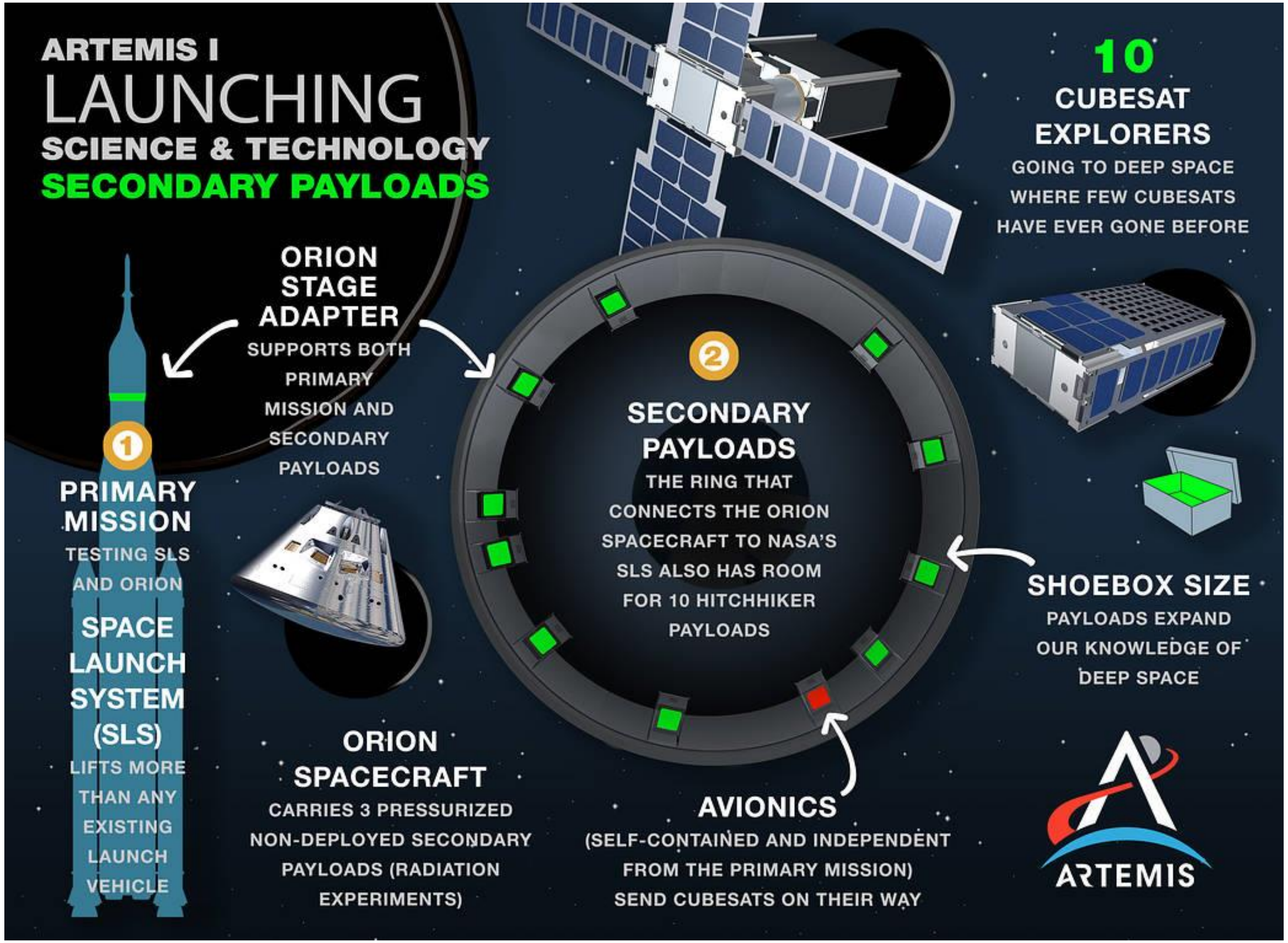

© JAXA/The University of Tokyo


© NASA/JPL-Caltech

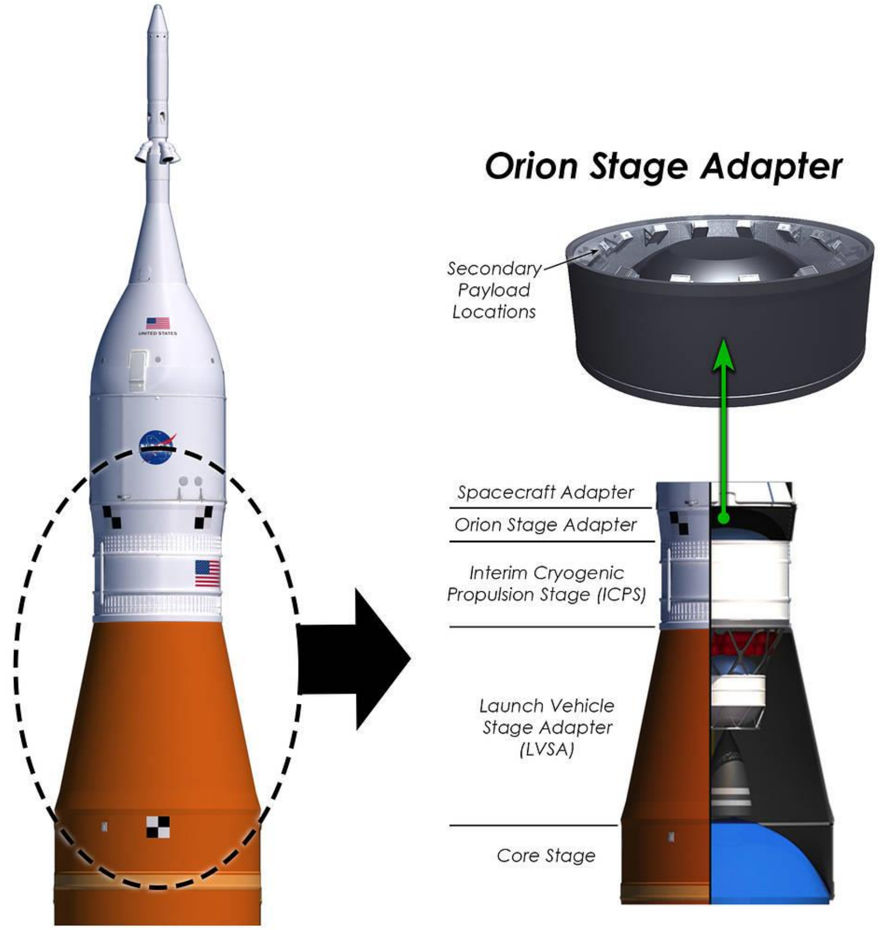
3.4. CubeSats on ARTEMIS I Mission



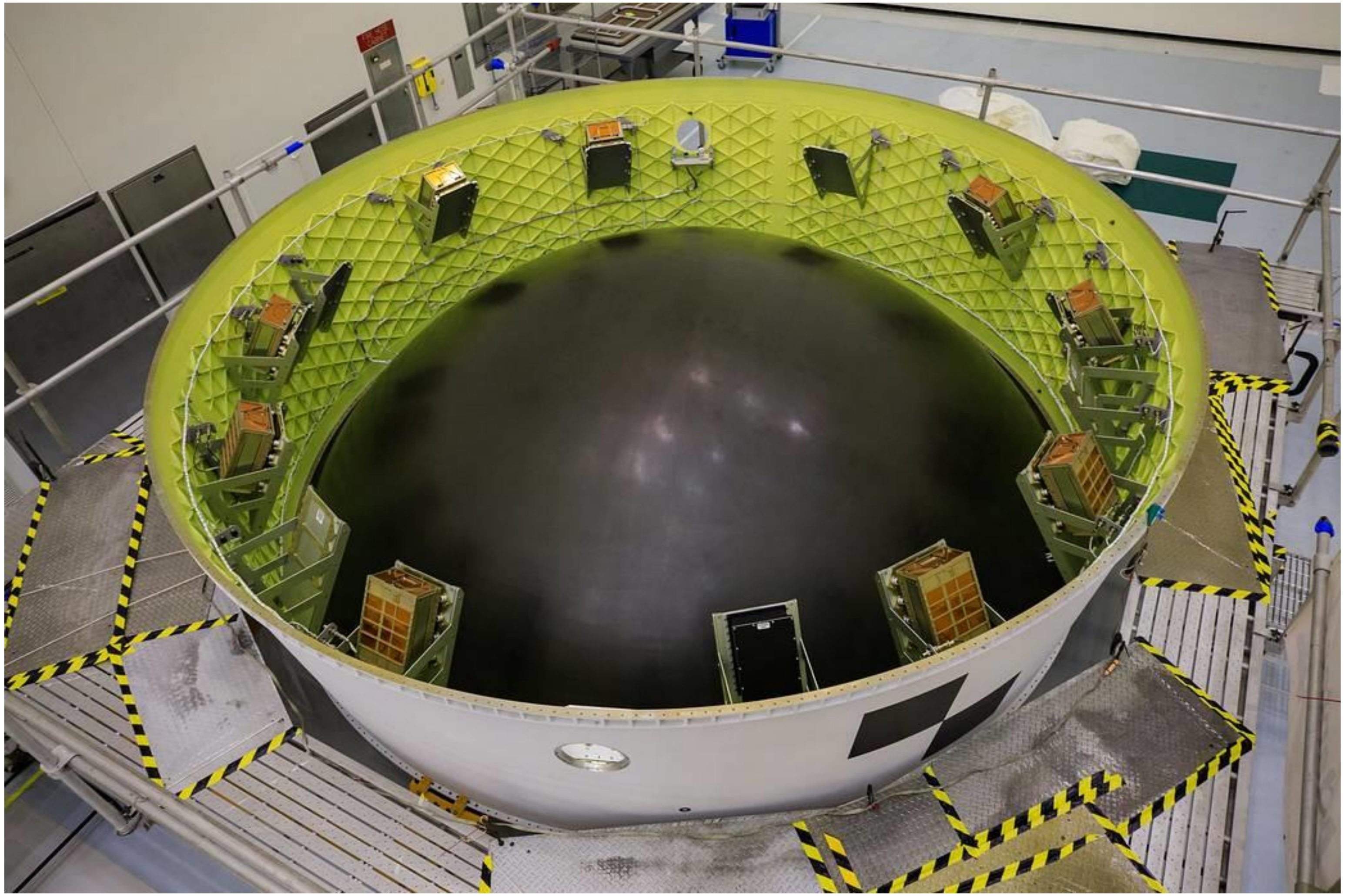
3.4. CubeSats on ARTEMIS I Mission



3.4. CubeSats on ARTEMIS I Mission



Space Launch System (Block 1 Configuration)



3. Characteristics and Capabilities of CubeSat

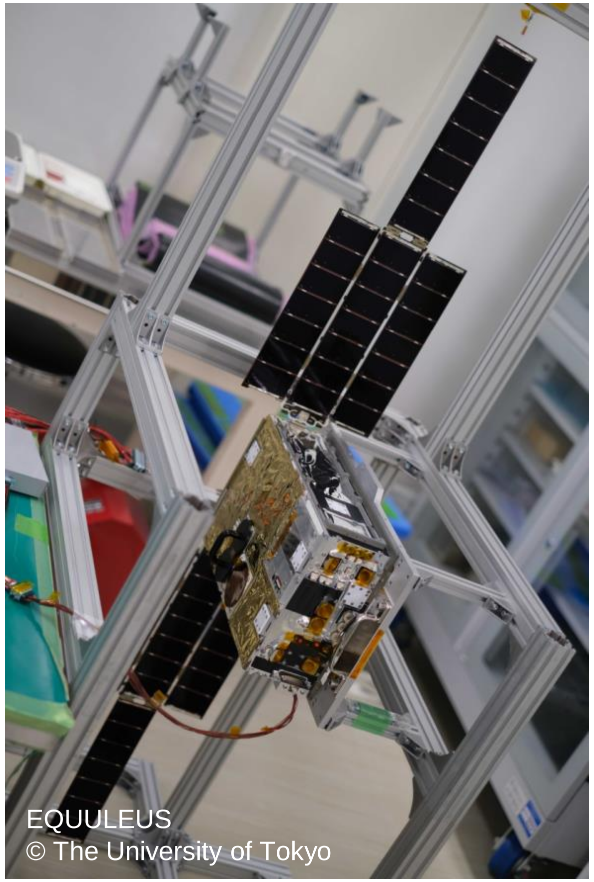
3.4. CubeSats on ARTEMIS I Mission

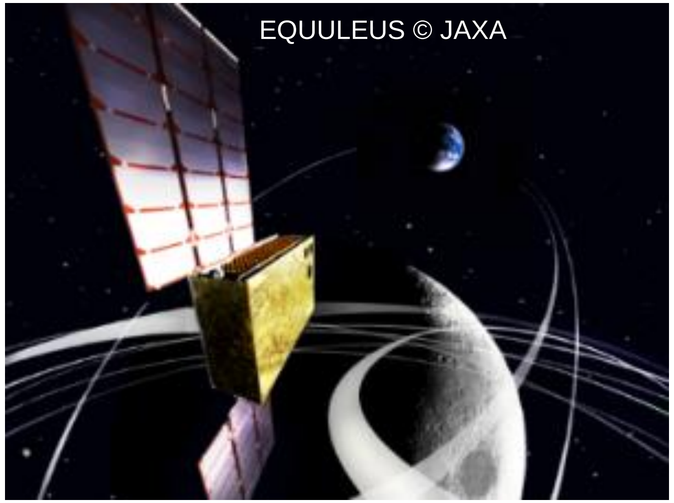
<u>6U CubeSat EQUULEUS</u> (JAXA, University of Tokyo)

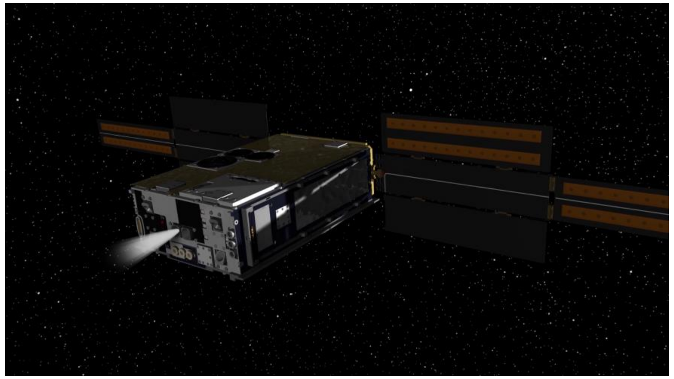
- Low-thrust trajectory control techniques using water thrusters
- Heading to Earth-Moon Lagrange point, with multiple sensors

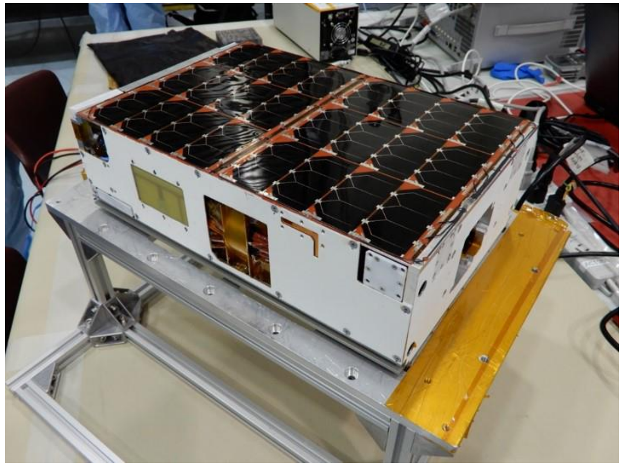
<u>6U CubeSat OMOTENASHI</u> (JAXA)

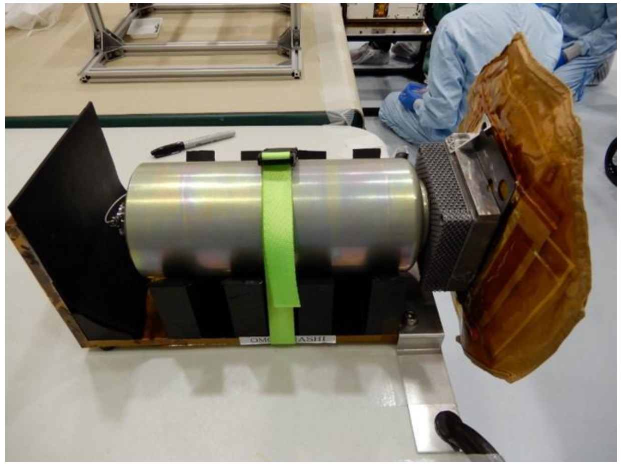
- Semi-hard lander on to the lunar surface
- Low-cost technologies to land and explore the lunar surface


EQUULEUS
© The University of Tokyo

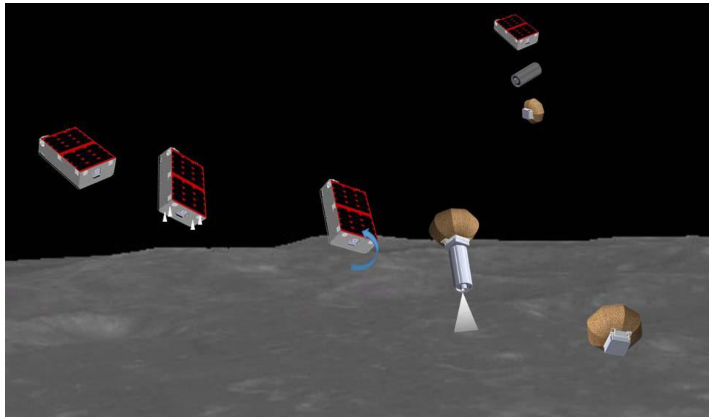

EQUULEUS © JAXA







© JAXA



© JAXA

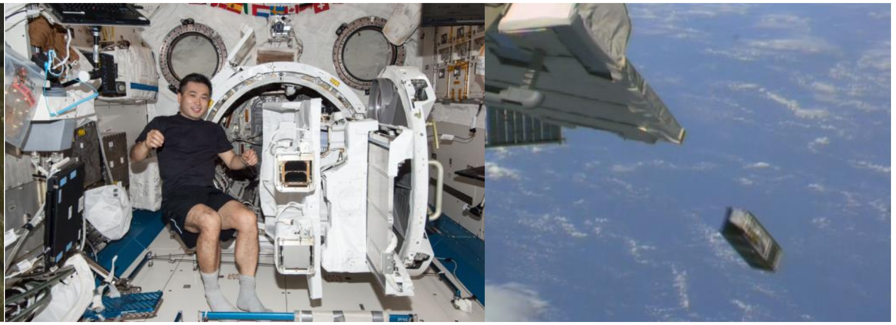
4. Launch Opportunities for CubeSats

4. Launch Opportunities for CubeSats

4.1. KiboCUBE Academy Launch Opportunity

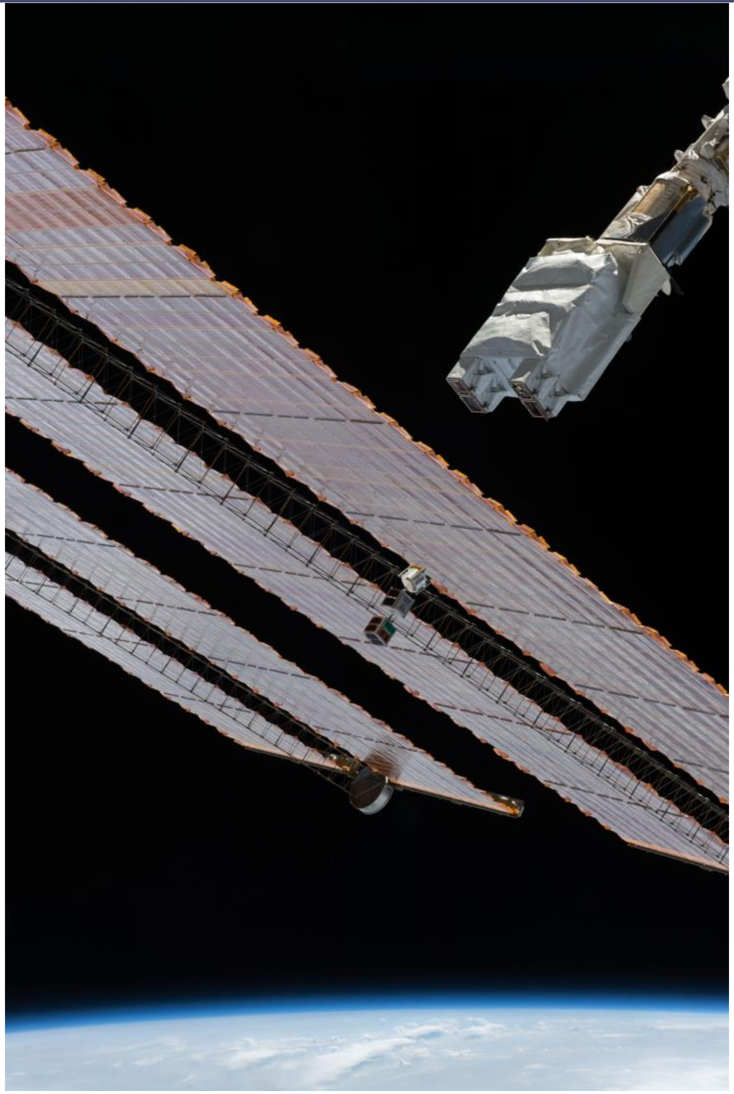
- KiboCUBE Academy provides deployment opportunities from the ISS Kibo module.
- The possible launch vehicle can be one of the transfer vehicles to the ISS:
  - HTV-X: JAXA H-II Transfer Vehicle
  - Dragon: SpaceX
  - Cygnus: Orbital Sciences Corporation
- The launch environment is different in each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

CubeSat Transfer to the ISS © JAXA



Deployment from the ISS © JAXA

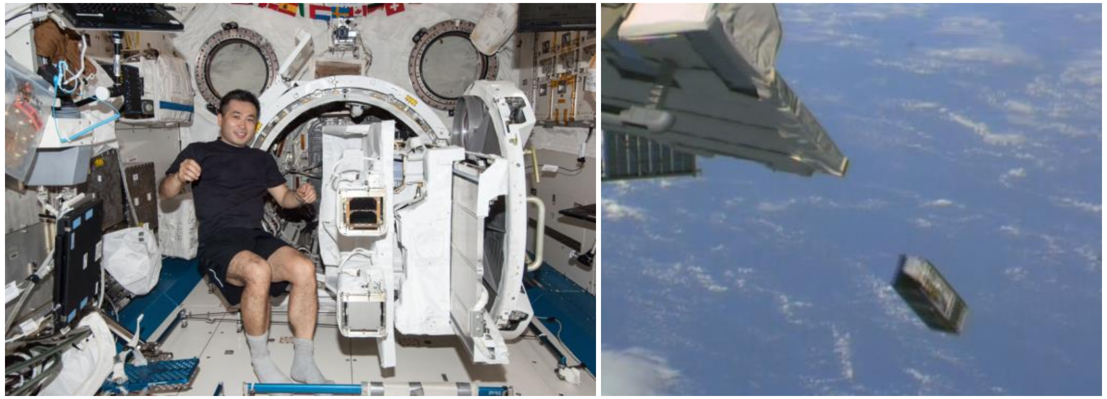
4.2. CubeSat Deployment from the ISS



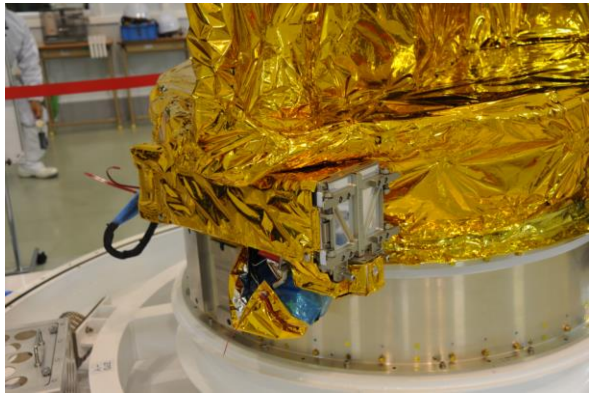
4. Launch Opportunities for CubeSats

4.3. Japanese CubeSat Launch Opportunities

- Deployment from the International Space Station (ISS) *KiboCUBE Academy
  - Launch is provided by H-IIB/H-III 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

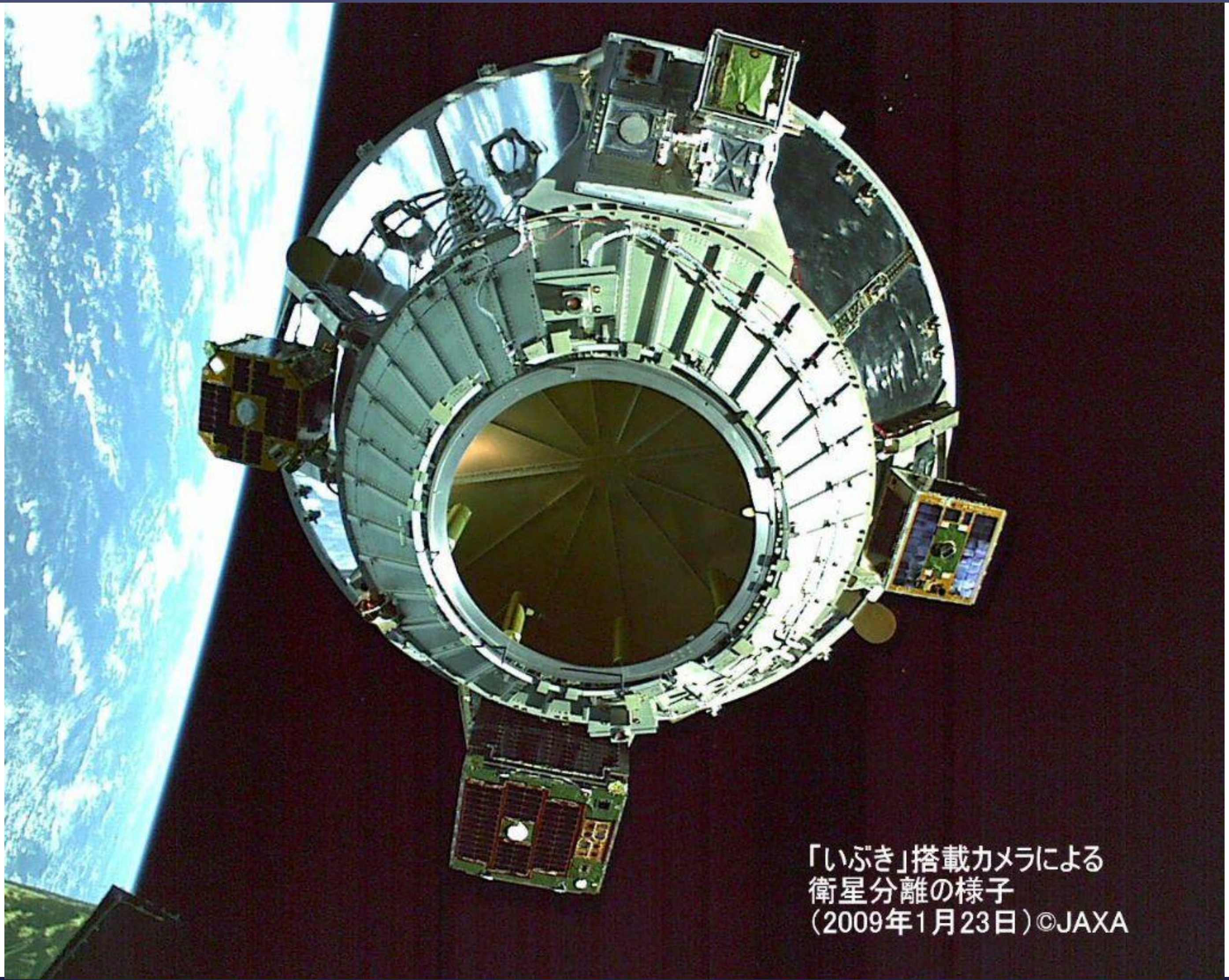


Direct launch (Epsilon Rocket) © JAXA

4. Launch Opportunities for CubeSats

4.4. 50-kg-class Micro-satellites Deployment from the ISS

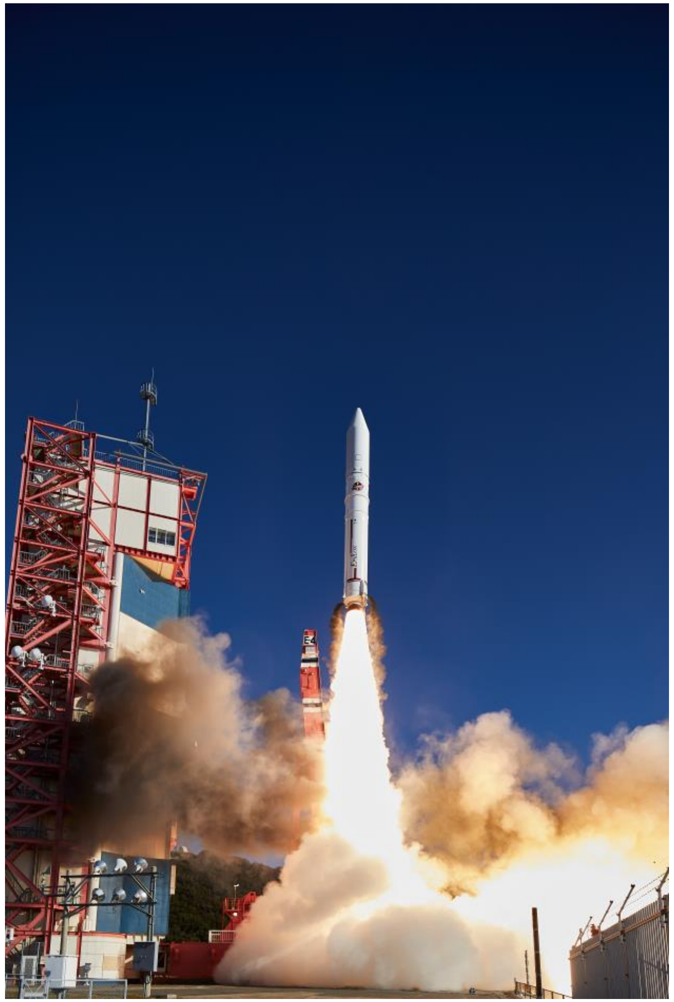
4.5. CubeSats and Micro-Satellites Launch by H-IIA



4. Launch Opportunities for CubeSats

4.6. CubeSats and Micro-Satellites Launch by Epsilon

JAXA Innovative Satellite Technology Demonstration Program



4. Launch Opportunities for CubeSats

4.7. 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

5.1. Hands-on Space Engineering Education

<u>Space Education through Small Satellite Projects</u>

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

© Tohoku University

5.2. 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.

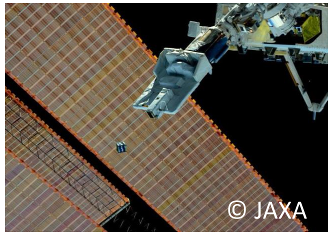
RWASAT-1

- 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.


© JAXA

© Kyutech


© University of Tokyo/Arkedge Space/RURA


© JAXA

5. Space Education through Satellite Projects

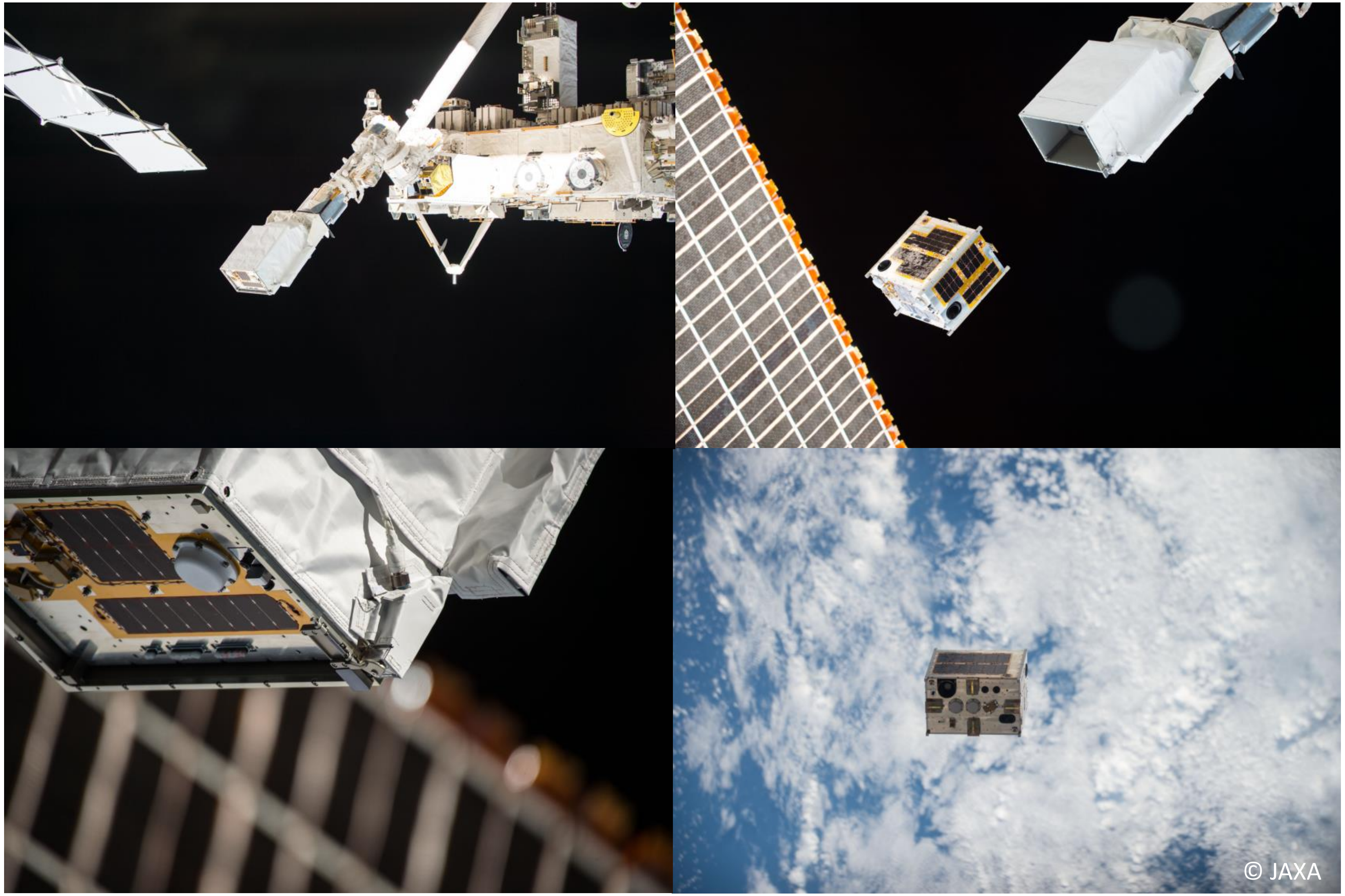
5.3. DIWATA-1 (Philippine Micro-satellite)

5. Space Education through Satellite Projects

5.3. DIWATA-1 (Philippine Micro-satellite)

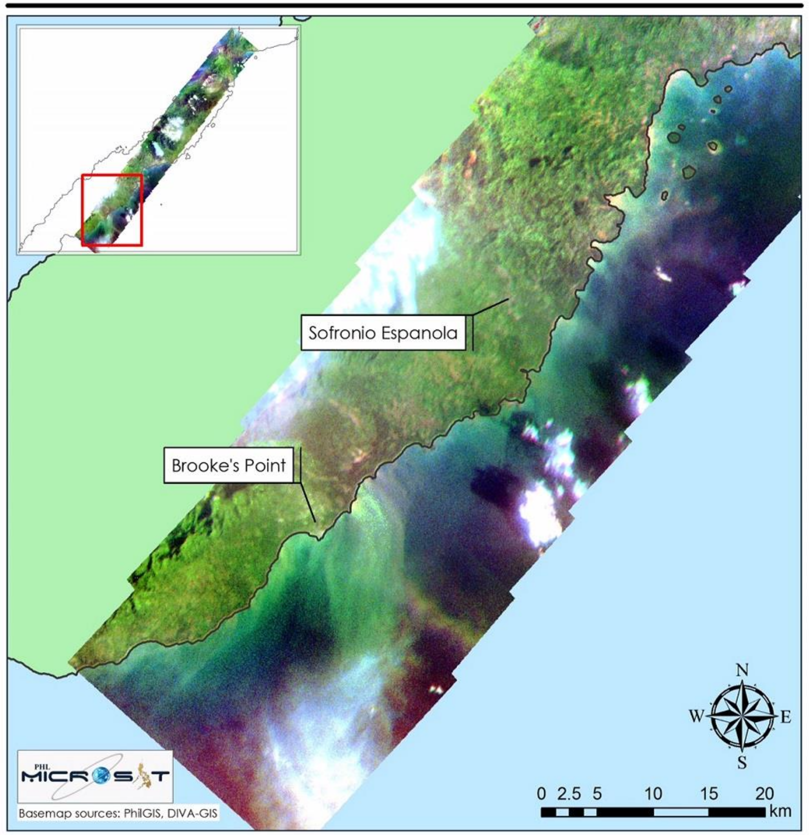
5. Space Education through Satellite Projects

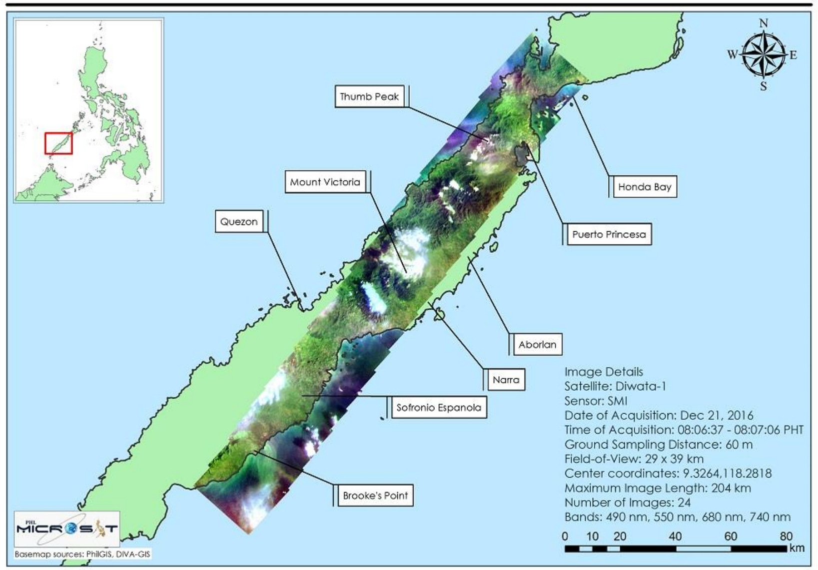
5.3. DIWATA-1 (Philippine Micro-satellite)

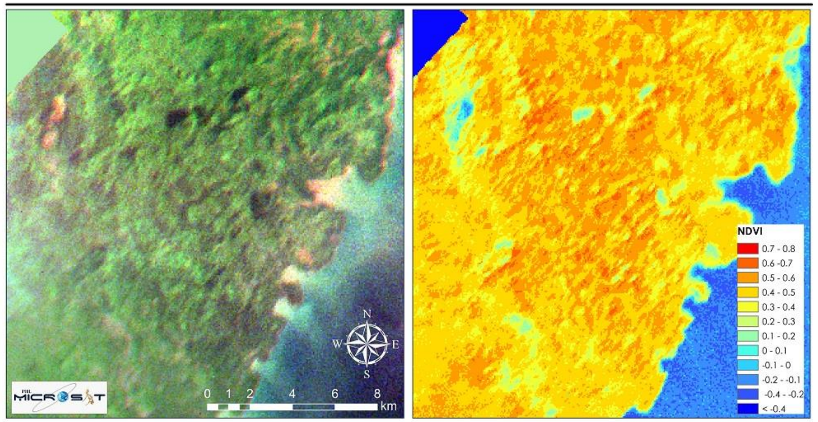


5. Space Education through Satellite Projects

5.4. 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

5.5. UNISEC Space Engineering Education Activities

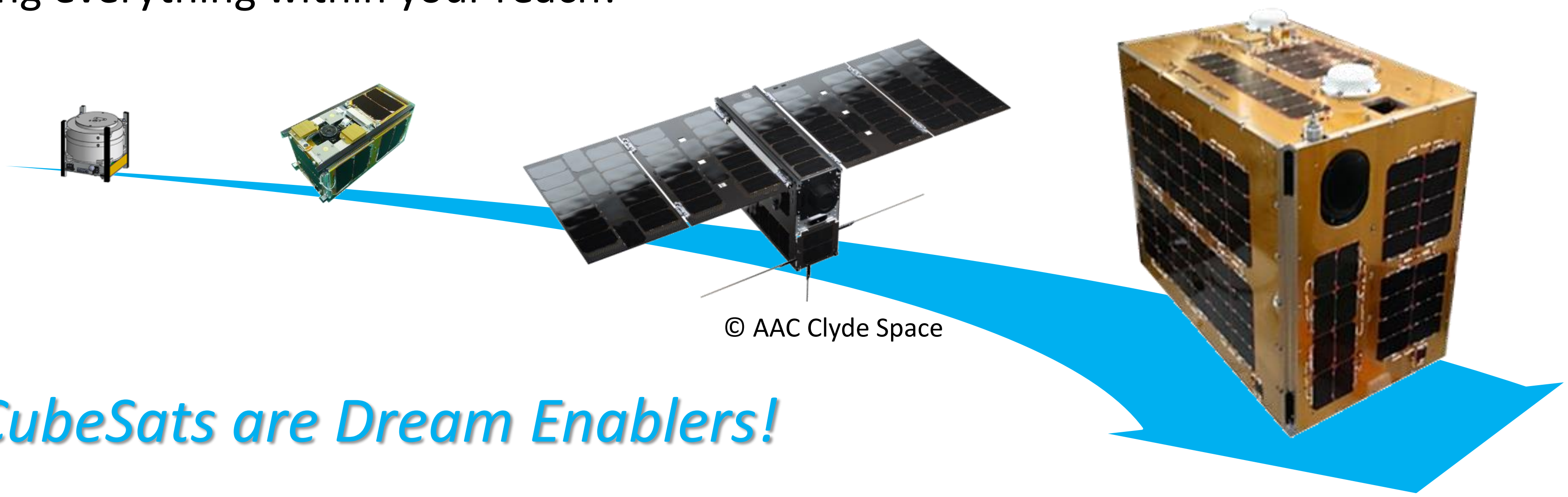
University Space Engineering Consortium

6. CubeSats are Dream Enablers

6.1. 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!

6.2. 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 to foster innovation and technological advancement.

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.