KiboCUBE Academy

Live Session #3-1

Introduction of CubeSat projects “BIRDS”

Kyushu Institute of Technology

Laboratory of Lean Satellite Enterprises and In-Orbit Experiments

Professor Ph.D. Mengu Cho

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

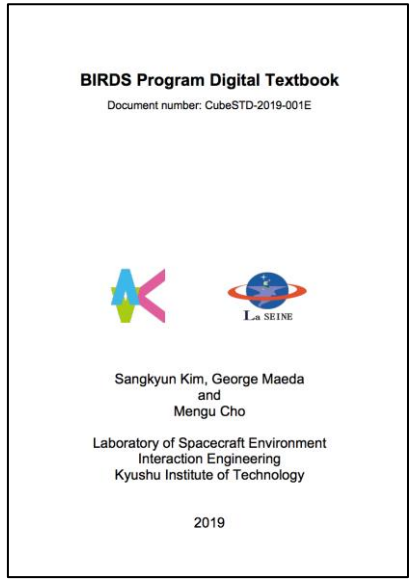
UNISEC University Space Engineering Consortium JAPAN

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

Contents

References

1. KiboCUBE Academy on-demand lecture 3-2, “CubeSat for Capacity Building”
   - Also available as KiboCUBE Academy 2021 - Day 3 - https://www.youtube.com/watch?v=t1ixA8D62cE
2. BIRDS Program Digital Textbook
3. International Academy of Astronautics (IAA) study group 4.18, “Definition and Requirements of Small Satellites Seeking Low-Cost and Fast-Delivery”, final report,
   https://lean-sat.org/nsat/pdf/sg418finalreport.pdf



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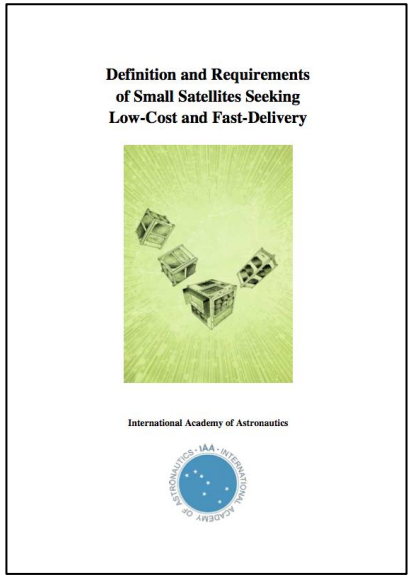
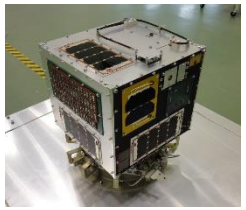
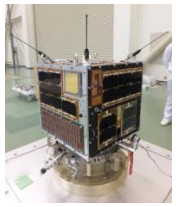
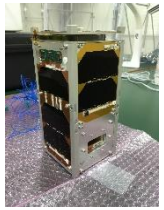
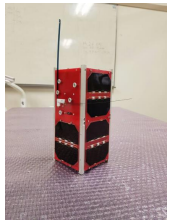
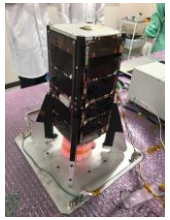


Ref.2

1. Lecturer introduction



Mengu Cho, Ph.D.

Position:

(*since 2018)
(**since 2020)

2004 - Professor, Department of Space Systems Engineering*
Director, Laboratory of Lean Satellite Enterprises and In-Orbit Experiments **
Kyushu Institute of Technology, Japan
2021 – Visiting Researcher, Chiba Institute of Technology, Japan
2014 - Visiting Professor, Nanyang Technological University, Singapore
2013 - Coordinator, Nations/Japan Long-term Fellowship Programme, Post-graduate study on Nano-Satellite Technologies (PNST)

Research Topics:

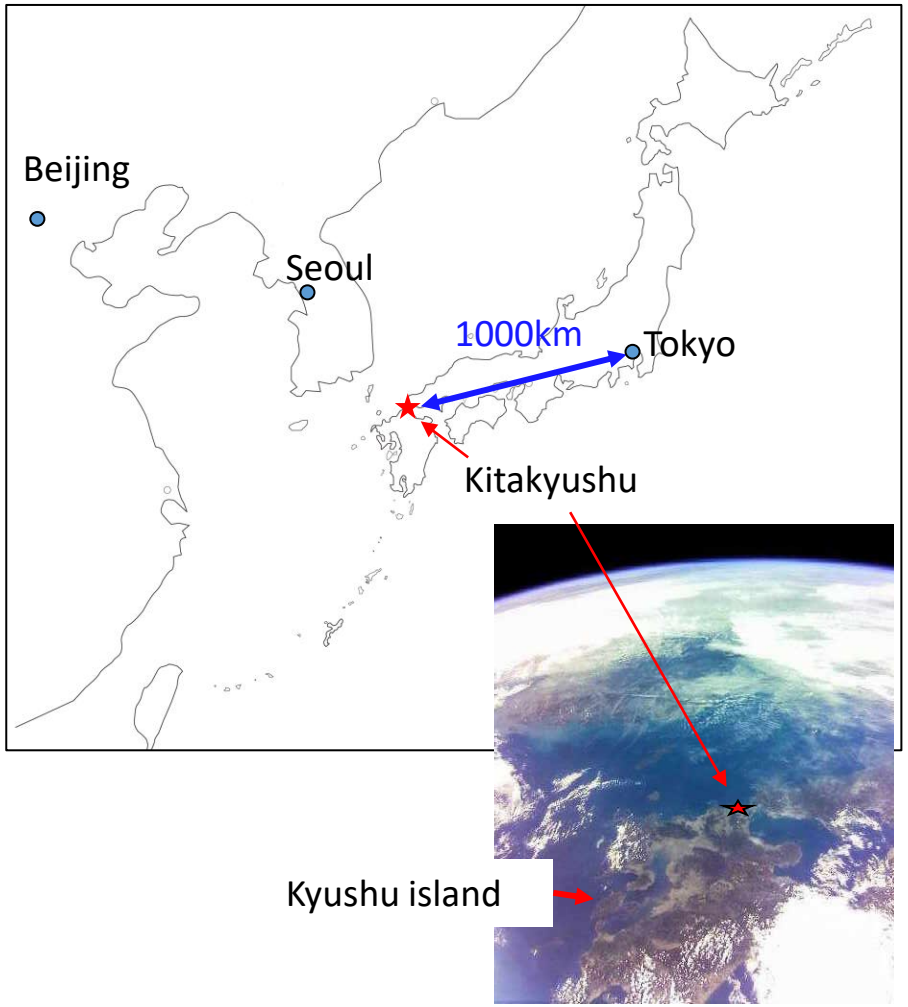
Lean Satellite, Spacecraft Environment Interaction

2. Introduction to Kyutech

2. Introduction to Kyutech

2.1 Kyushu Institute of Technology (Kyutech)

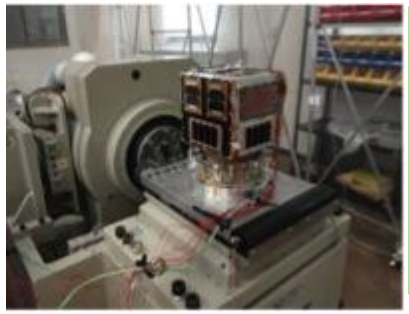
- A national university founded in 1909
  - 4,200 Undergraduate students
  - 1,300 Graduate students
  - 360 Faculty members
  - Engineering, Computer science, Life-science
- Located in the Kitakyushu region
  - Population of more than 1million



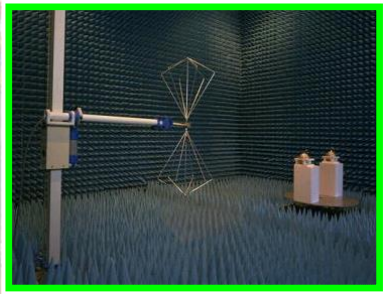
2. Introduction to Kyutech

2.2 Center for Nanosatellite Testing

To be capable of doing all the tests for a satellite up to 50cm, 50kg



Vibration

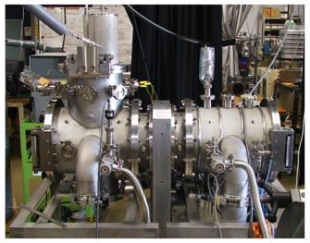


EMC & Antenna pattern

Pressure & Leak

Thermal vacuum

Assembly & Integration



Thermal vacuum

Thermal cycle

Shock

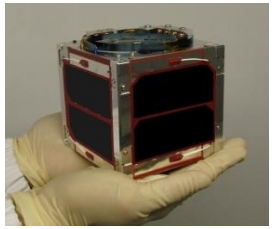
Outgas
(ASTM E595)

α&ε measurement

Tested more than 70 satellites since 2010 including satellites from overseas (e.g. Egypt, Costa Rica, Singapore, Malaysia, Vietnam, Thailand, etc.)

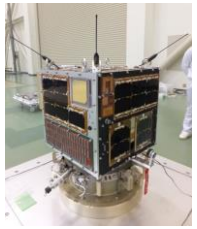
2. Introduction to Kyutech

2.3 Kyutech Satellite Heritage

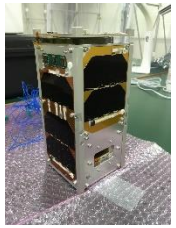


HORYU-1 (1U)
2006-2010
Not launched

HORYU-II
2010-2012
Launch 2012/5/18



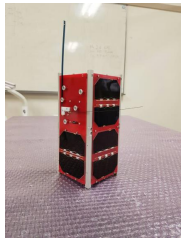
HORYU-IV
2013-2016
Launch 2016/02/17



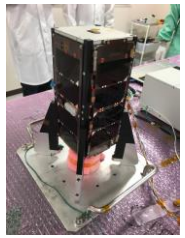
AOBA VELOX-III
2014-2016
ISS Release 2017/01/19

BIRDS-I constellation
2015-2017
ISS release 2017/07/07

BIRDS-II constellation
2016-2018
ISS release 2018/08/10



SPATIUM-I
2016-2018
ISS release 2018/10/06



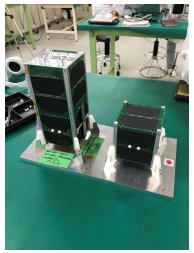
AOBA VELOX-IV
2016-2018
Launched 2019/01/18

BIRDS-III constellation
2017-2019
Launched 2019/04/18

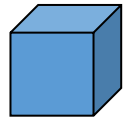
BIRDS-IV constellation
2018-2020
Launched 2021/03/14

KITSUNE
2019-2021
Launch, 2022

FUTABA
2018~2021
Launch, 2022



BIRDS-5J, -5Z, -5U
2022



MITSUBA
2022年

Satellite name
Satellite development period
Launch/ISS release date

World's No.1 academic small satellite operator since 2018

(Bryce Space Technology report on SmallSats by the Numbers)

3. Capacity Building Activities at Kyutech

3. Capacity Building Activities at Kyutech

3.1 Small satellite proliferation

No.	Country	Satellite name	Launch Year
1	Columbia	Libertad 1	2007
2	Switzerland	SwissCube	2009
3	Hungary	Masat-1	2012
4	Romania	Goliat	2012
5	Poland	Pwsat 1	2012
6	Ecuador	NEE-01 Pegaso	2013
7	Estonia	EstCube 1	2013
8	Peru	PUCPSat-1	2013
9	Lithaunia	LitSat 1 LitaunicaSat 1	2014
10	Uruguay	Antelsat	2014
11	Iraq	Tigrisat	2014
12	Finland	Aalto 2	2017
13	Bangladesh	BRAC Onnesha	2017
14	Ghana	Ghanasat-1	2017
15	Mongolia	Mazaalai	2017
16	Slovakia	SKCUBE	2017
17	Latvia	Venta-1	2017
18	Kenya	1KUNS-PF	2018
19	Costa Rica	Irazu	2018
20	Bulgaria	EnduroSat One	2018
21	Bhutan	BHUTAN-1	2018
22	Jordan	JYAT (JO-97)	2018
23	Sri Lanka	Raavana 1	2019
24	Nepal	NepaliSat-1	2019
25	Rwanda	RWASAT-1	2019
26	Guatemala	Queztzal-1	2020
27	Slovenia	TRISAT	2020
28	Monaco	OSM-1 CICERO	2020

List of CubeSats launched as the first national satellite

3. Capacity Building Activities at Kyutech

3.2 Issues of capacity building activities

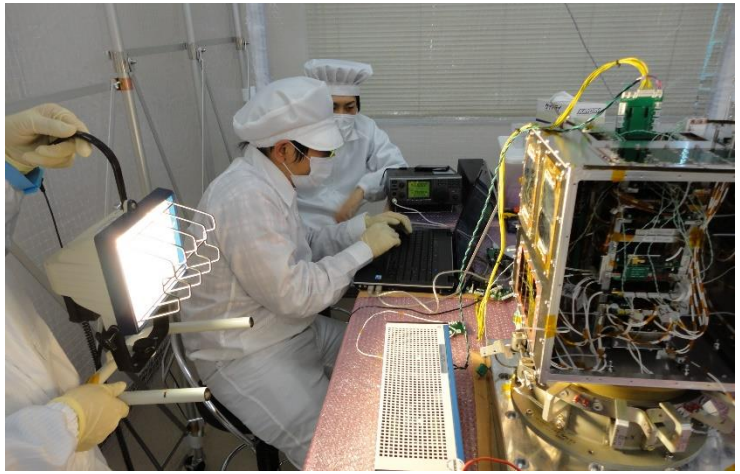
- Small satellites are ideal entrance for developing countries to join the space sector
- Demand for capacity building through small satellites
- Various training programs via agencies, companies and universities in space faring countries
  - Often tied with sales of satellites (big or small)
  - Not successful, especially if the training is done in agencies or companies
    - Lack of hands-on experience
    - Not covering the entire system life cycle of satellite
- Key points
  - Experience the **complete cycle** of designing, building, testing and operating through **hands-on**
  - Strategy for **sustainability** after the training

3. Capacity Building Activities at Kyutech

3.3 Space Engineering International Course (SEIC)

- Started in April 2013 at Graduate School of Engineering, Kyutech to support PNST

1. Research towards a Master or Doctoral degree
2. On-the-job training such as space environment testing workshop
3. Project Based Learning (PBL) through a space project
4. Space-related lectures in English



3. Capacity Building Activities at Kyutech

3.4 **UN/Japan Long-term Fellowship Programme**

- A part of United Nations Office of Outer Space Affairs (UNOOSA) Basic Space Technology Initiative (BSTI) since 2011
- 2011: Doctor on Nano-Satellite Technologies (DNST) initiated at Kyutech
  - 2 Doctoral students selected per year
  - Kyutech provided financial support
- 2013: **Post-graduate study on Nano-Satellite Technologies (PNST)** initiated
  - 2 Masters students selected per year
  - 4 Doctoral students selected per year
  - MEXT (Japanese government) fellowship support
- **2018 - : PNST 2nd and 3rd term**
  - 3 Masters students selected per year
  - 3 Doctoral students selected per year
  - MEXT (Japanese government) fellowship support
  - **Application Deadline: January 10, 2022 (for 2022 October admission)**

3. Capacity Building Activities at Kyutech

3.5 PNST/SEIC Student Composition

Country	Number of students	Country	Number of students	Country	Number of students
Nigeria	7	Vietnam	7	Paraguay	4
Ghana	4	Thailand	7	Mexico	3
Uganda	3	Philippine	7	Costa Rica	3
Egypt	3	Malaysia	5	Columbia	3
Zimbabwe	3	Indonesia	4	Peru	2
Sudan	3	Myanmar	2	Honduras	1
Algeria	2	Singapore	1	El Salvador	1
Ethiopia	1	Laos	1	Trinidad and Tobago	1
Kenya	1	Cambodia	1	Brazil	1
Namibia	1	China	1	Ukraine	2
Morocco	1	Mongolia	4	Romania	1
Turkey	3	Bhutan	6	France	9
Palestine	1	Bangladesh	4	Spain	2
		Sri Lanka	3		
		Nepal	3		
		India	1		

Distribution of foreign students enrolled up to 2021 October

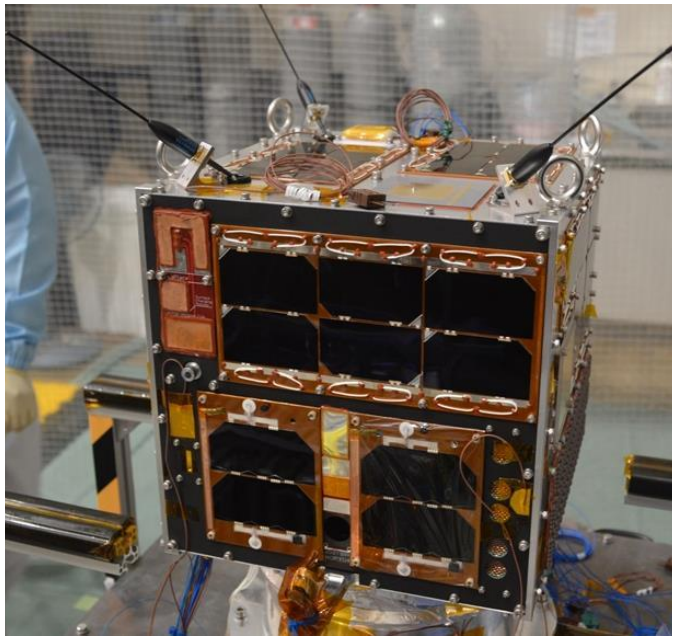
126 foreign students from 42 countries enrolled over 9 years

PNST/SEIC won Space Development Utilization Award (Minister of Foreign Affairs) in 2017

3. Capacity Building Activities at Kyutech

3.6 HORYU-IV Project (2013~)

This is a mock-up (not a real satellite)



Launched on Feb. 17, 2016

44 members from 18 countries

First and second generations of PNST/SEIC students

3. Capacity Building Activities at Kyutech

3.7 Kyutech meets Ghana

Visit by Dr. Donkor, All Nations University College, Ghana, to Kyutech (2015 5.21)

The idea for an international satellite project was born that night

4. BIRDS Program

4. BIRDS program

4.1 Mission statement

Satellite program for non-space faring countries

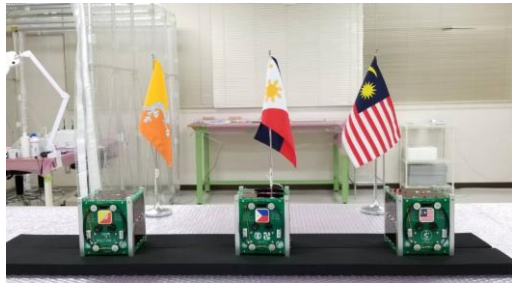
Mission Statement

By successfully building and operating the first national satellite,
make the foremost step toward indigenous space program at each nation.

BIRDS-I (2015-2017)

JAPAN GHANA MONGOLIA NIGERIA BANGLADESH

BIRDS-II (2016-2018)



BHUTAN PHILIPPINE MALAYSIA

BIRDS-III (2017-2019)

SRI LANKA NEPAL JAPAN

BIRDS-IV (2018-2020)

PHILIPPINE JAPAN PARAGUAY

BIRDS-V (2020-2022)



JAPAN ZIMBABWE UGANDA

4. BIRDS program

4.2 Outline

- 1U CubeSat constellation of
  - BIRDS-1: 5 satellites by **Bangladesh*, Ghana***, Japan, **Mongolia***, and Nigeria
  - BIRDS-2: 3 satellites by **Bhutan***, Malaysia and Philippine
  - BIRDS-3: 3 satellites by Japan, **Sri Lanka*** and **Nepal***
  - BIRDS-4: 3 satellites by Japan, Philippine and **Paraguay***
  - BIRDS-5: 3 satellites by Japan, **Zimbabwe*** and **Uganda***
- Made by students at Kyutech
- 2 years from concept design to disposal
- Released from ISS
- Network operation by multiple ground stations

**** First satellite for the country***

BIRDS-1 was first called “Joint Global Multi-Nation Birds” taking the first letter of each country. Later, it simply became “BIRDS”

Group photos of BIRDS-I, –II, –III, -IV and -V teams

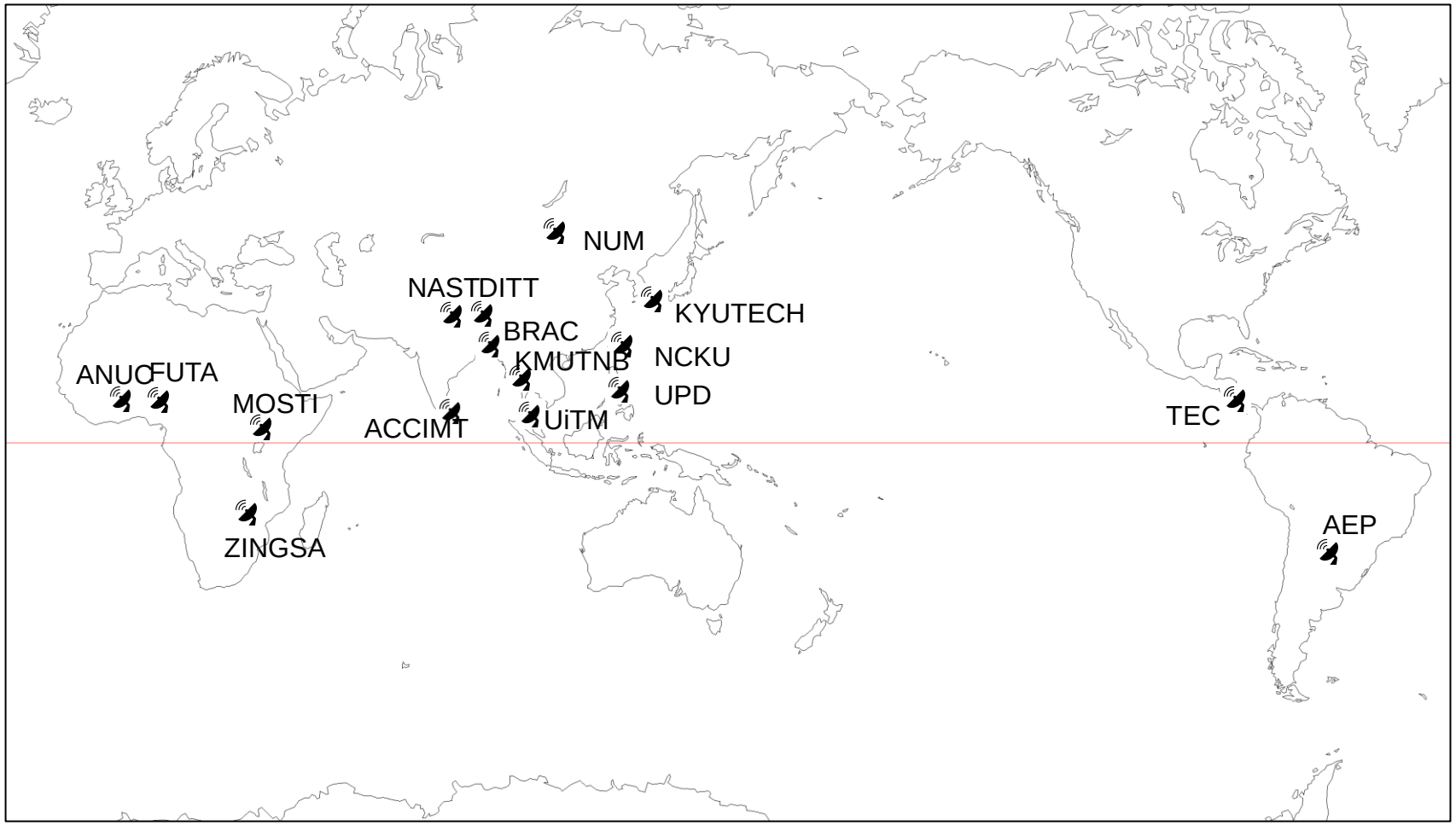
4.3 BIRDS partners

- BIRDS partners are made of universities, academic institutes or agencies.
- Each partner who owns a satellite pays
  - Launch cost
  - Hardware cost
  - Student cost (at least two students sent to Kyutech)
  - Ground station cost in each country
- Each partner is committed to initiate space education/research program
  - BIRDS graduates form its core

4. BIRDS program

4.4 BIRDS ground station network

BIRDS constellations are operated by a network of GSs in BIRDS partners



4. BIRDS program

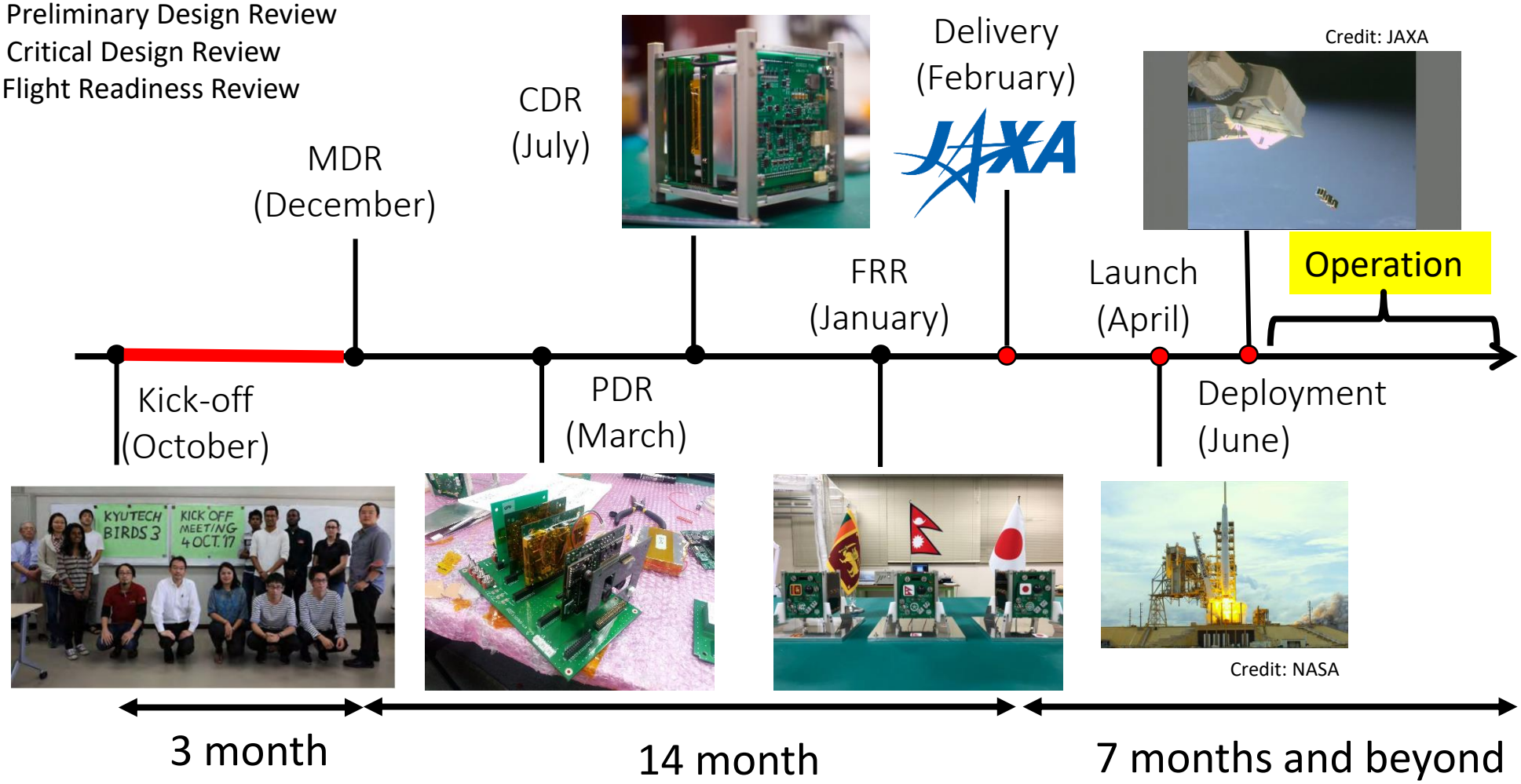
4.5 Fit into 2 years

- A short-term goal
  - Build and operate satellites
    - Give the students **confidence** that they can do it
- Long-term goal
  - Students initiate their own space program in home countries
  - The full mission success
    - **The former students successfully build and operate the second satellite in their home countries**
- Let students learn **the entire process** of a satellite project from beginning to end
  - Witness decision-making processes and then make decisions by themselves
- Fit the project within the degree timeline. 2 years maximum.
  - Select 1U CubeSat and ISS deployment as the platform for this training
- ***What 1U CubeSat can do is limited. But it is more important to gain the confidence and the experience as the first step***

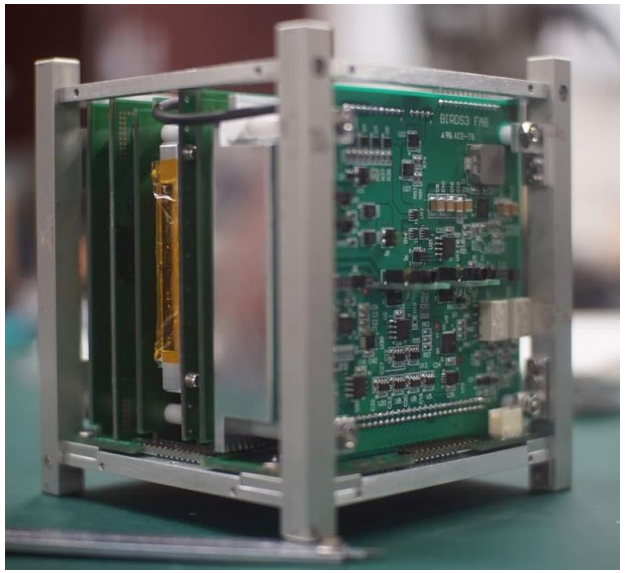
4. BIRDS program

4.5 Fit into 2 years

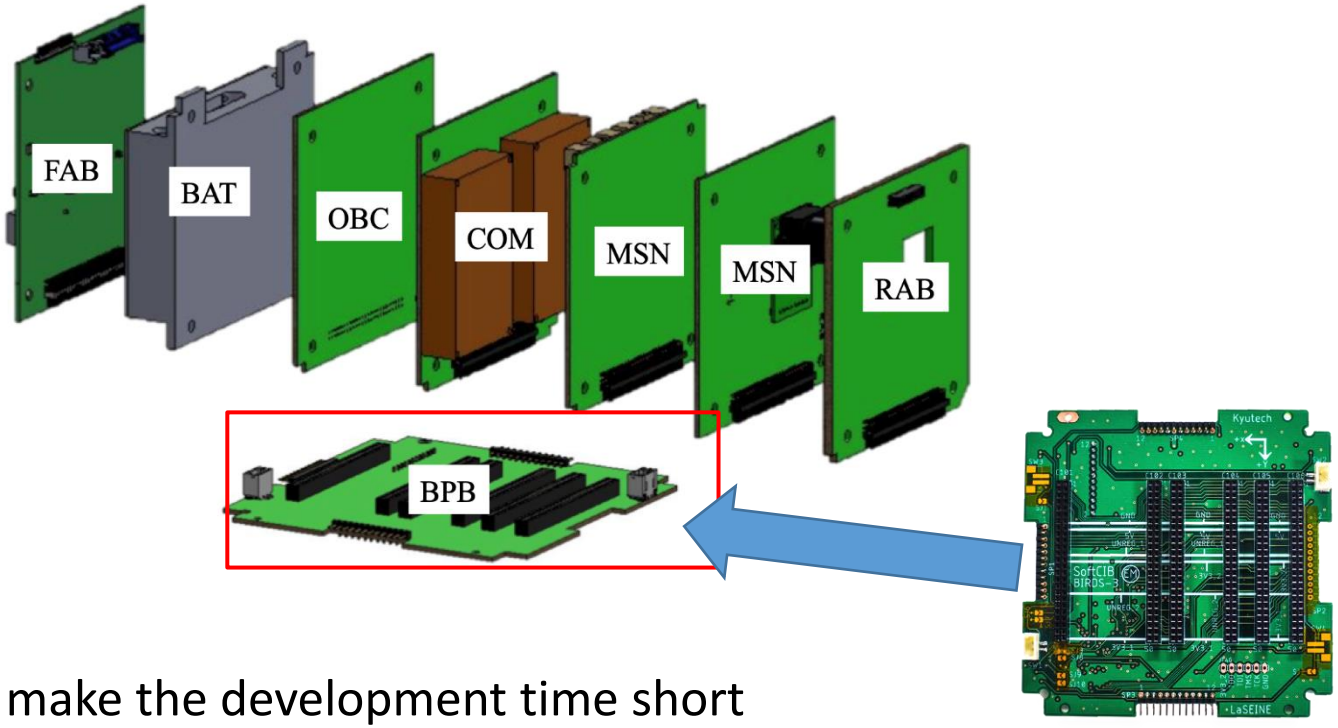
MDR: Mission Definition Review
PDR: Preliminary Design Review
CDR: Critical Design Review
FRR: Flight Readiness Review



- Each satellite has the same design (per generation)
- Harnessless design
- Each satellite uses the same frequency (UHF/VHF amateur radio)



Easy assembly and disassembly



The satellite is designed to make the development time short

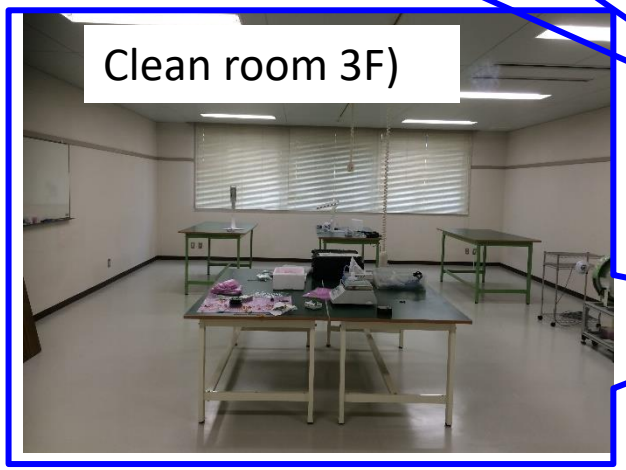
- The BIRDS program experiments the lean satellite approach
  - Lean satellites seek to deliver value to the customer (the end-user or the purchaser) or the stakeholder at minimum cost and in the shortest possible schedule by minimizing waste.
  - Achieve the maximum reliability within the budget and schedule constraints. Evaluate, prioritize and mitigate risks properly to fit into the small budget and short schedule.
- When the students continue the space program in their home country, they have to adopt a lean approach so that the program can run with a small team and at minimum cost.
- In the BIRDS program, the overall satellite development activity can be done within a radius of 30 m. The development occurs on campus.
- **The students are encouraged not to use e-mail unless they need to broadcast to all the team members.**

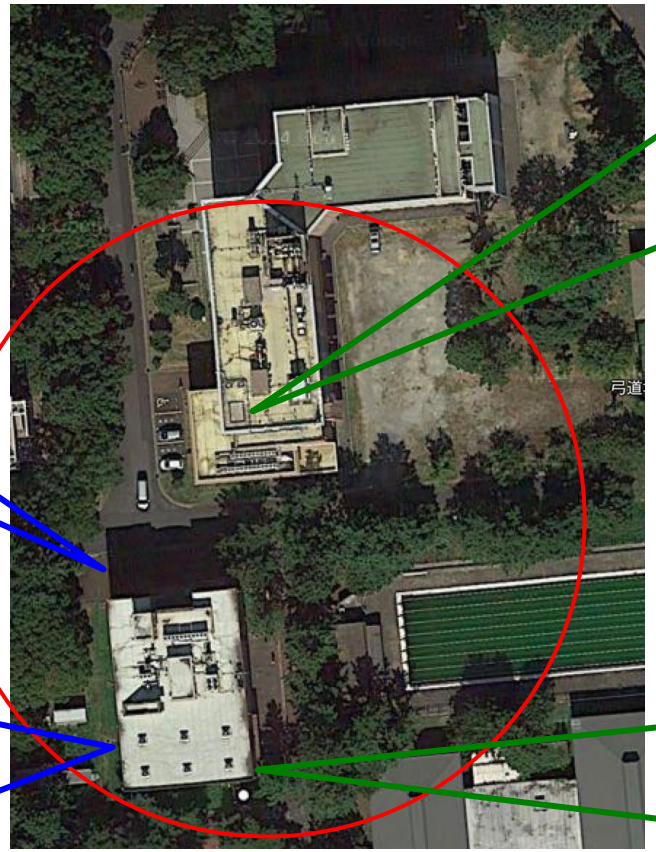
See Ref. 3 for more details about Lean Satellite

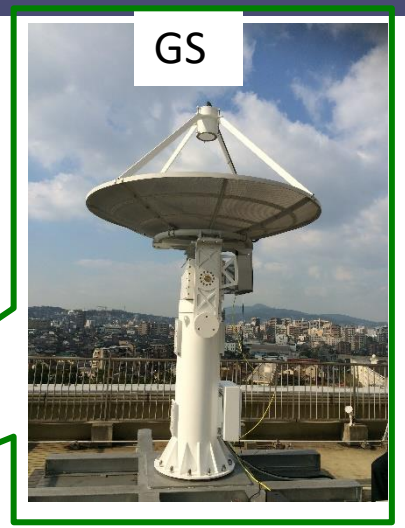
4. BIRDS program

4.7 Lean Satellite Approach Design and Configuration

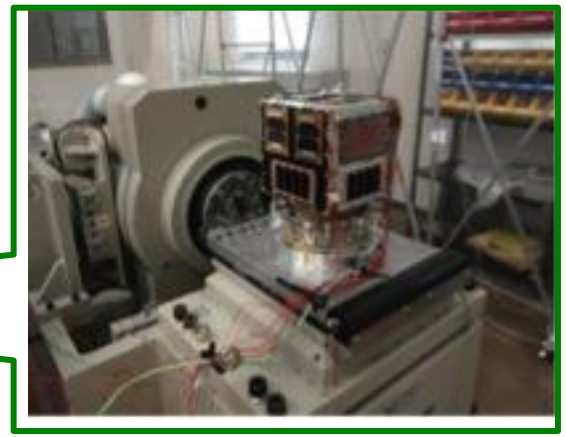
- Minimize waste of “waiting” and “moving”







Test facility(1F)



4. BIRDS program

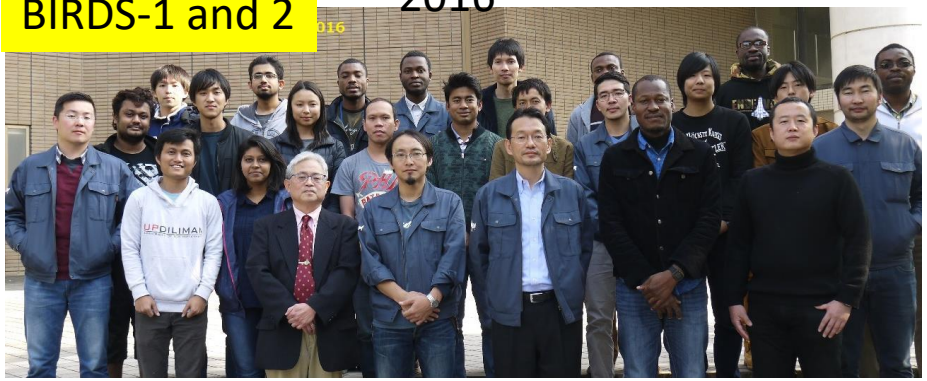
4.8 Knowledge and know-how transfer

2015

BIRDS-1 only

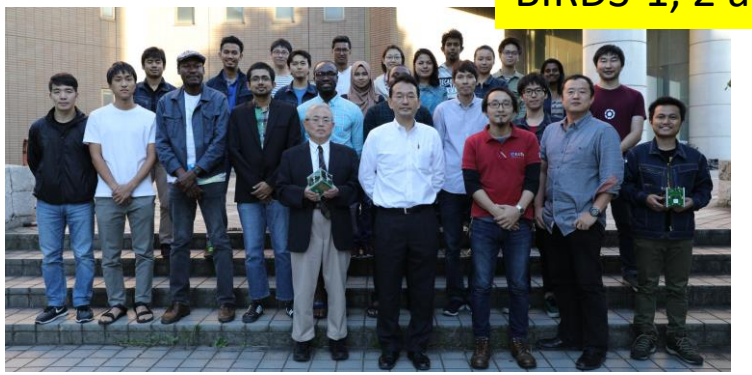
BIRDS-1 and 2

2016



2017

BIRDS-1, 2 and 3



BIRDS-1, 2, 3 and 4

2018

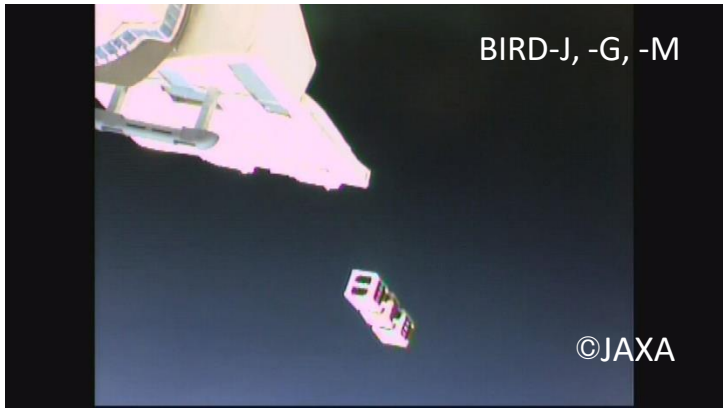
BIRDS-3, 4 and 5

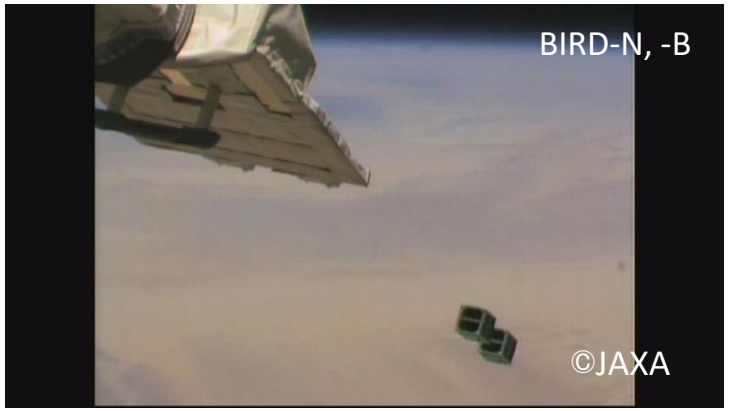
2020

Overlapping generations to transfer knowledge and lessons person-to-person directly

4. BIRDS program

4.9 BIRDS-1





Satellite delivery on February 8, 2017

(16 months from kick-off to delivery)

Released successfully to orbit from ISS on July 7, 2017

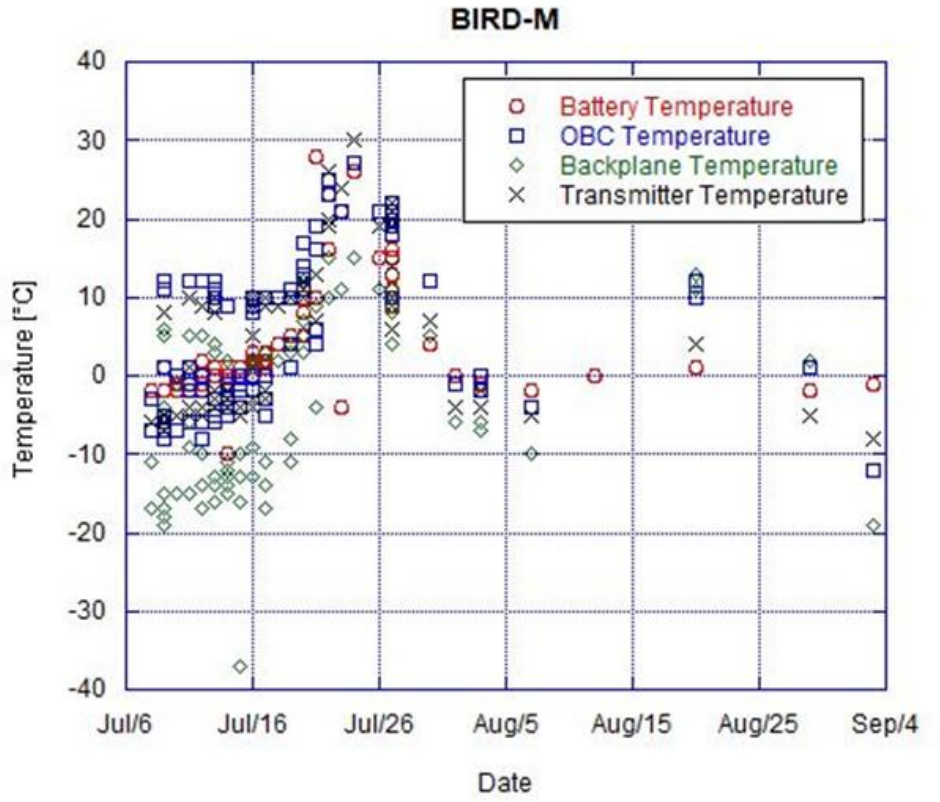
Heard beacon signals from all five satellites

4. BIRDS program

4.9 BIRDS-1

Won **2017 GEDC (Global Engineering Deans Council) Airbus Diversity Award** out of 45 entries from 18 countries as a successful example of **using diversity to effectively conduct engineering education**

4.14 Results (BIRDS-1)

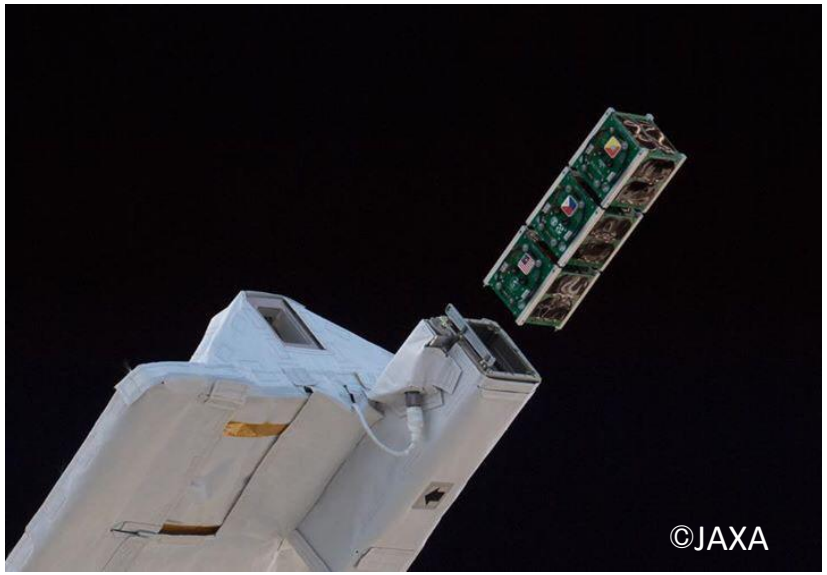


- Heard the beacon data until satellites de-orbitted 22 months later
- No uplink success
- Over-confidence in VHF patch antenna

4. BIRDS program

4.10 BIRDS-2

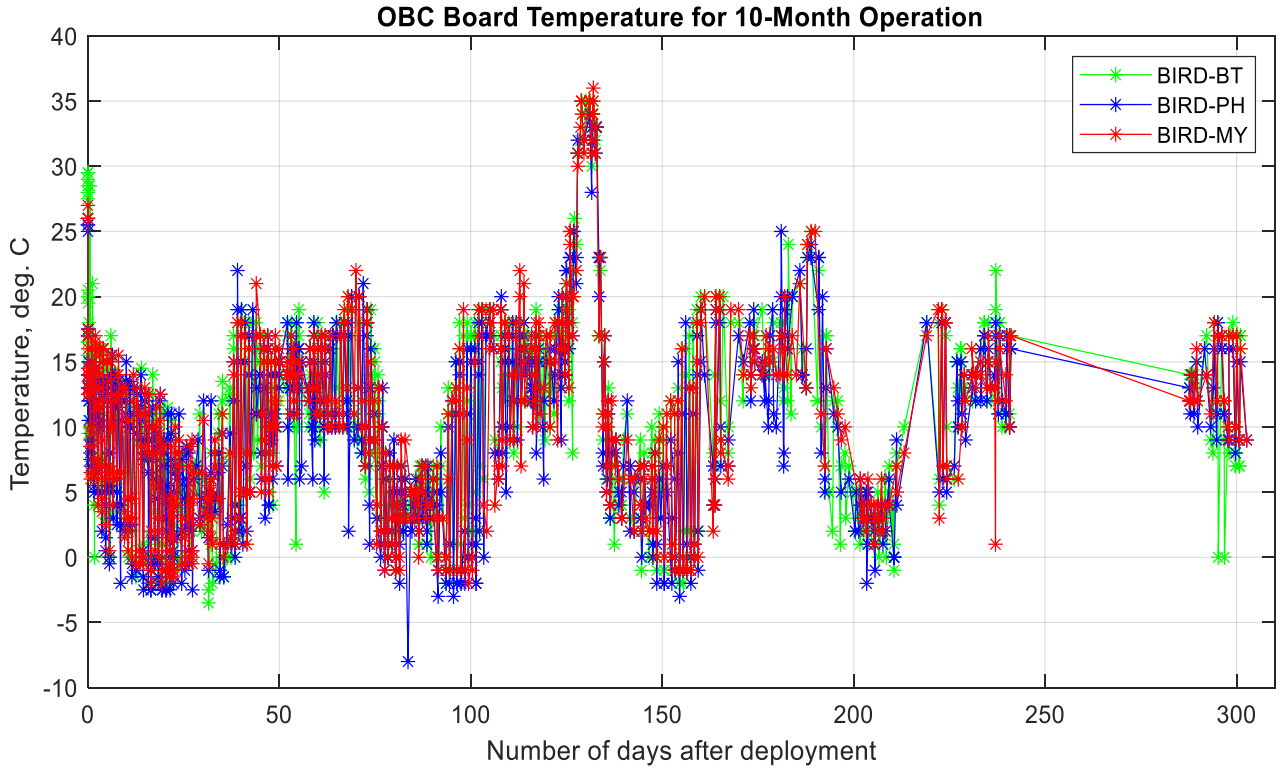
Satellite delivery on May 17, 2018



Released on Aug.10, 2018

4. BIRDS program

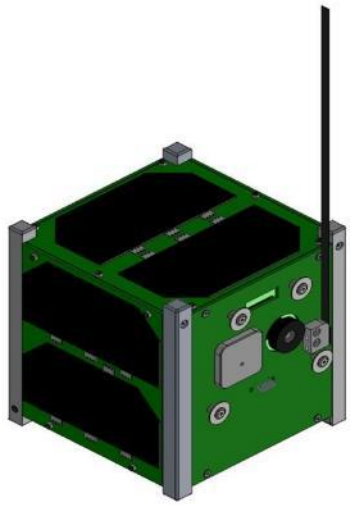
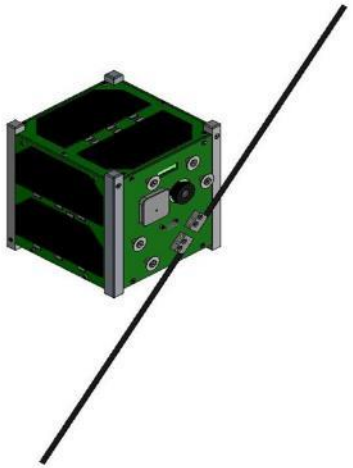
4.15 Results (BIRDS-2)



- Much stronger beacon signal thanks to the deployable antenna
- Obtained basic housekeeping data throughout 2 years in orbit
- Very little success in uplink due to internal noise generated by EPS

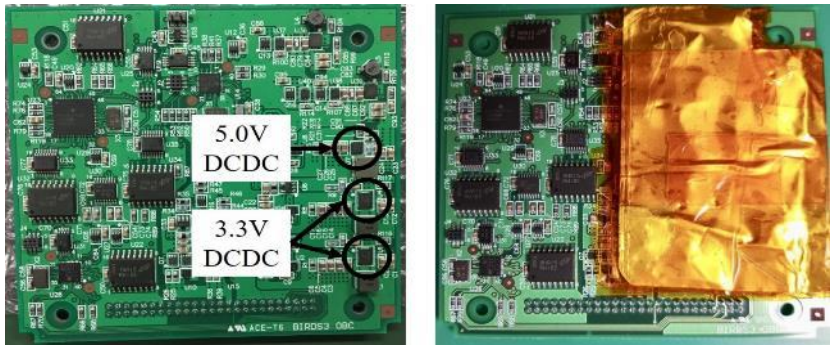
4. BIRDS program

4.16 Improvement from BIRDS-2 to BIRDS-3

EM-1 (Monopole Antenna)	EM-2/ FM (Dipole Antenna)
	

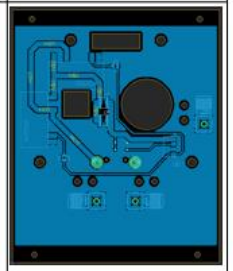
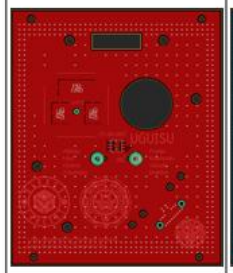
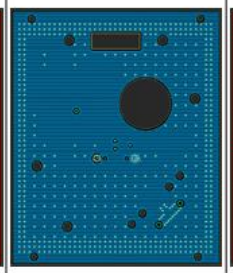
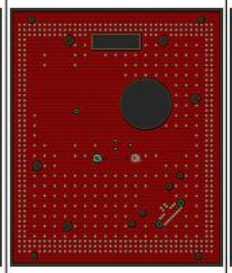
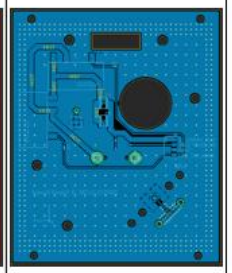
BIRDS3 EM-1 design was similar to BIRDS2

Shielding



OBC/ EPS board

FAB

	1st layer	2nd layer	3rd layer	4th layer
EM-1		None	None	
FM				

Antenna PCB design with more GND

Ground station upgraded

Linear Polarization Antenna

Circular Polarization Antenna

4. BIRDS program

4.11 BIRDS-3

Satellite delivery on February 18, 2019

Released on Aug.10, 2018

4. BIRDS program

4.17 Results (BIRDS-3)

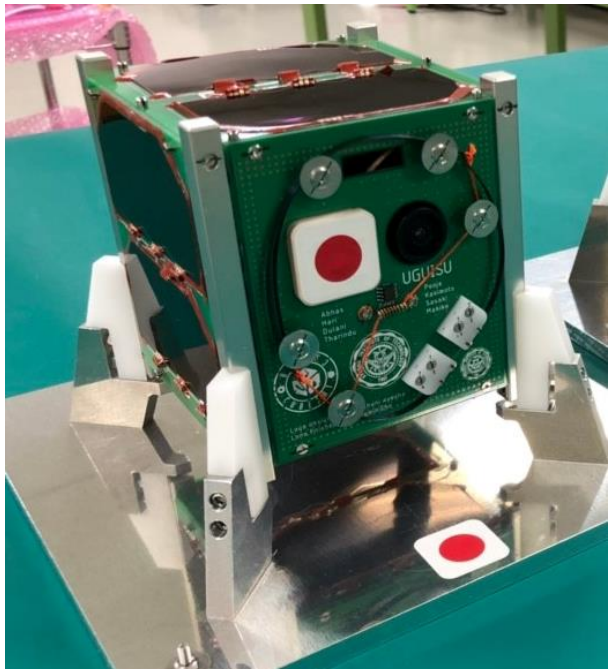


Photo of Sri Lanka island

- Capturing the images of Nepal, Sri Lanka and Japan
- Demonstration of electrical functionality of LoRA devices in orbit
- Demonstration of software configurable backplane

- Implemented the lessons from BIRDS-1 and BIRDS-2 experiences
- Fully operational for two years
- Full mission success was achieved

4. BIRDS program

4.12 BIRDS-4

Satellite delivery on September 25, 2020

Released on March 14, 2021

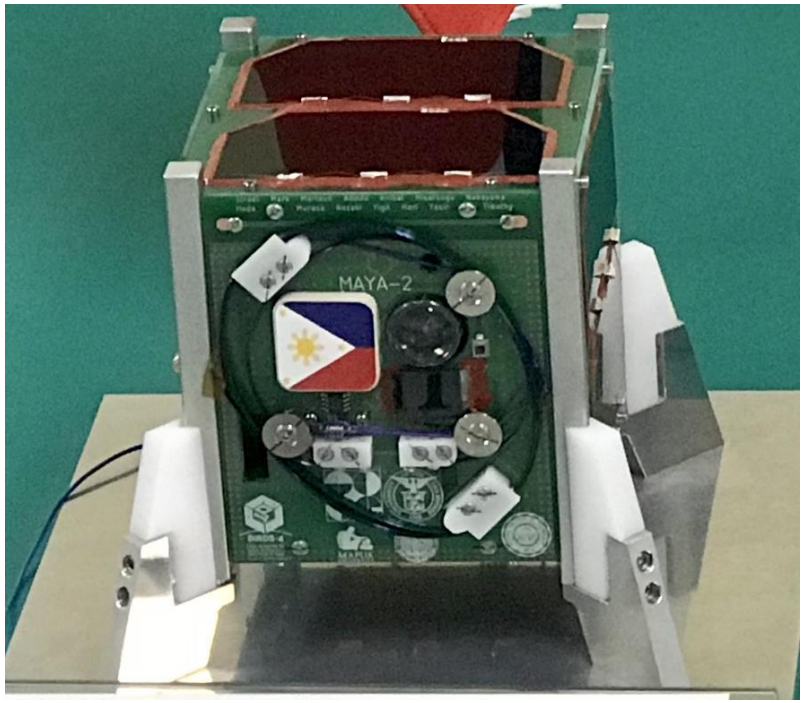


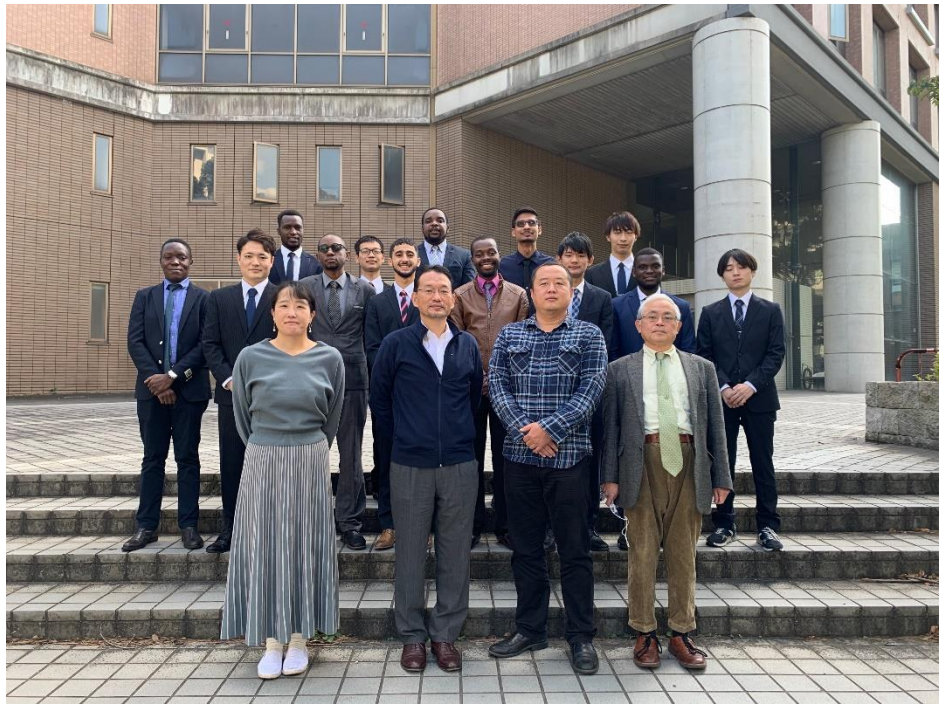
Photo of ISS just after deployment

- Capturing the images of Paraguay, Philippine and Japan
- Body mounted antenna
- Pervoskite solar cell
- APRS/DP via VHF
- Total ionization dose effects

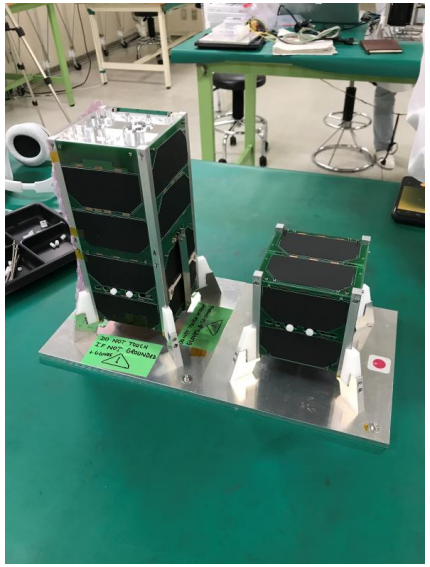
- 2 satellites missing after 1 month due to power management mistakes
- 1 satellite remains and continues the mission for more than 8 months

4. BIRDS program

4.13 BIRDS-5



Member group-photo

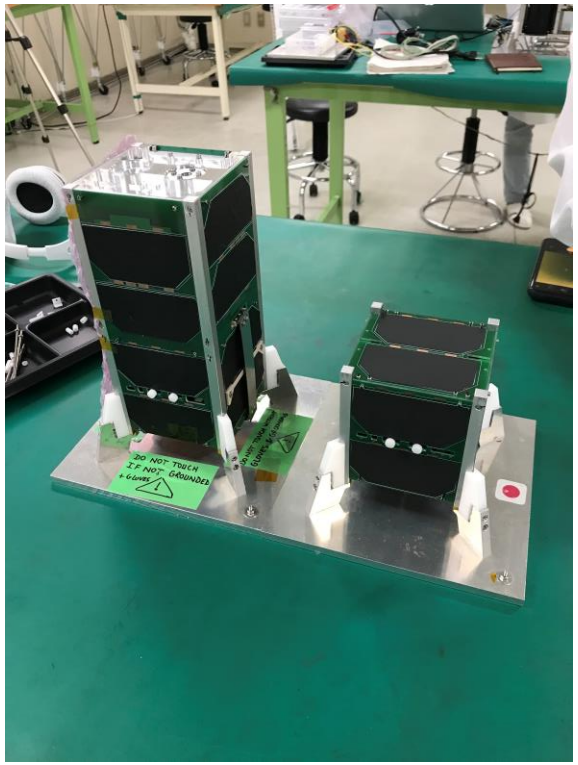


Satellite Engineering Model

To be deployed in 2022

4. BIRDS program

4.19 BIRDS-5



Engineering model

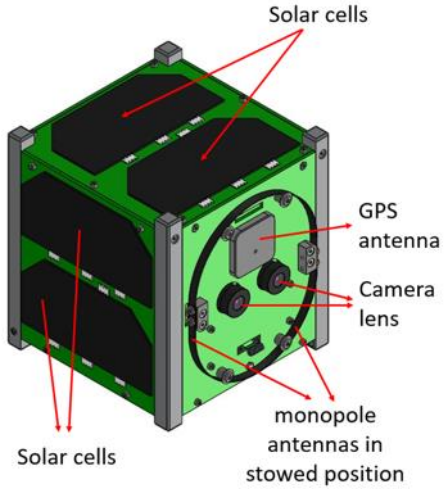
- 2 x 1U satellites and 1 x 2U satellite
- 2U satellite carries a scientific payload to measure energetic particles in space
- Except the additional payload, internal components are the same between 1U and 2U
- Missions
  - Land/water monitoring by multi-spectral cameras
  - Data collection from ground sensor terminals via VHF
  - Image classification onboard using neutral network
  - Data distribution via smartphone application

4. BIRDS program

4.20 Evolution

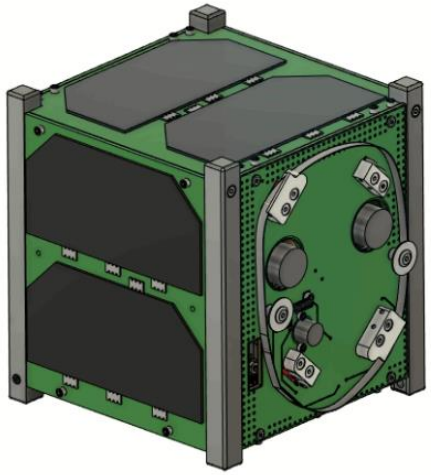
BIRDS-1

BIRDS-2



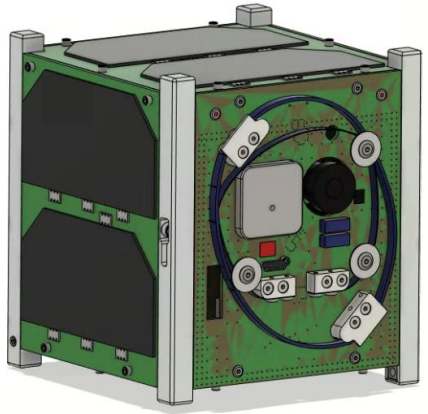
Deployable antenna
UHF uplink

BIRDS-3



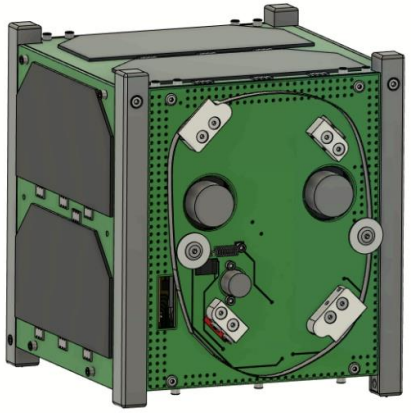
Dipole antenna
New OBC/EPS

BIRDS-4



3xDeployment switch

BIRDS-5



No rail switch

- BIRDS bus evolved to implement the lessons of the previous generations and to adapt to changes in launcher requirements
- Since BIRDS-3 changes are becoming minor

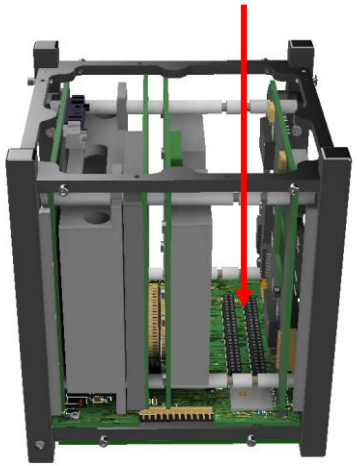
4. BIRDS program

4.21 Adoption of BIRDS Bus

2U based on BIRDS-2
Simple mission using UHF

6U based on BIRDS-3/4
High power + Li-ion battery
High speed communication
Active attitude control

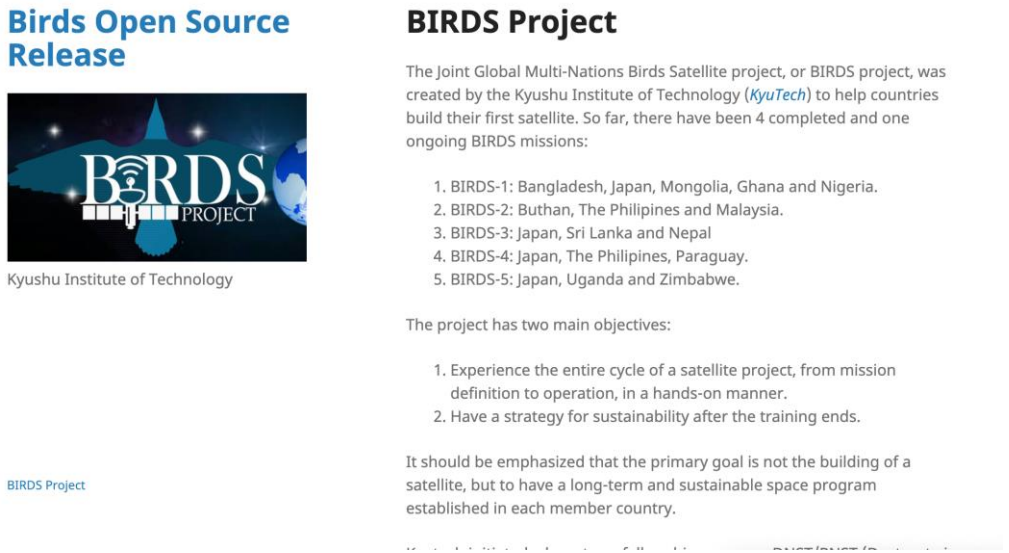
Mission payload slots



BIRDS-5 platform

- Other satellite projects at Kyutech utilize BIRDS bus to speed-up the development processes

- Make the information related to BIRDS bus available in the public domain
  - Hardware, Software, Ground station, drawing, parts list, ICD, procedure, reports, etc.
- Purpose
  - Assist BIRDS alumni make the second satellites in their home countries
  - Make BIRDS bus available as an affordable CubeSat bus
  - Make BIRDS bus a defacto-standard as a CubeSat bus for human resource development
- Maintenance
  - User group made by BIRDS alumni
  - Use GitHub
- Contents
  - BIRDS-3 (already available)
  - BIRDS-4
  - BIRDS-5 (after FM delivery in early 2022)
  - Operation data of BIRDS-3,-4,-5
- License
  - MIT License



https://birdsopensource.github.io/

4. BIRDS program

4.23 Strategy for sustainability

- Aiming at university space programs in non-space faring countries
- Often a national space program suffers disruption because of political and economical disturbances
- University space program is immune to the external disturbances.
- To start with the minimum budget, a university is an ideal place.
  - CubeSat chosen as a training platform.
  - Affordable enough at university budget level
- The university space program cannot grow forever.
  - Need to hand over the national space program to government or to industry
- Even after handing over the big projects to an outside body, the university can continue its own space research and education
  - Need to provide continuously human resources to the national space program

4. BIRDS program

4.24 BIRDS network

- Consists of BIRDS partners (stakeholders)
- Human network
  - Formed during intensive two years project by “living under the same roof”
  - Assist infant space programs in surviving “hard times” and other difficulties
- Ground station network
  - The backbone of the inter-university network
  - Enable constellation operation in future
    - Doing space research with small satellite constellation for creating interesting data

4. BIRDS program

4.25 Cross-Border Inter-University Collaboration on Space Research and Education

- Mission
  - “To advance the peaceful use of outer space for the benefit of humanity by using a network of universities conducting space research and education”
- Each member institution of the BIRDS Network (BIRDS partners) will launch its own space research and education program.
- Annual workshops
  - Japan (2016), Ghana (2017), Mongolia (2018), Bangladesh (2019) and so on…

BIRDS workshop 2017 @Ghana

BIRDS workshop 2018 @Mongolia

BIRDS workshop 2019 @Bangladesh

5. Conclusion

5. Conclusion

- BIRDS program was introduced as an example of CubeSat program for capacity building
  - Unique educational program involving diverse cultural background
- Key points
  - Experience the **complete cycle** of designing, building, testing and operating through **hands-on**
  - Strategy for **sustainability** after the training
- Think as a broad program rather than as individual satellite projects
  - Improvements are made based on in-orbit experience
- Simple interface to serve as a CubeSat platform
  - Open-sourcing the satellite bus information

5. Conclusion

BIRDS 10 rules

- At the end of every BIRDS project kick-off meeting, the following 10 rules are shown

1. **No Excuse**
2. **Be on time**
3. **Respect others**
4. Be responsible
5. Watch schedule
6. Act as a team player
7. Have a long view
8. Be clean
9. Work hard
10. Have fun

Thank you very much.

[Disclaimer]
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