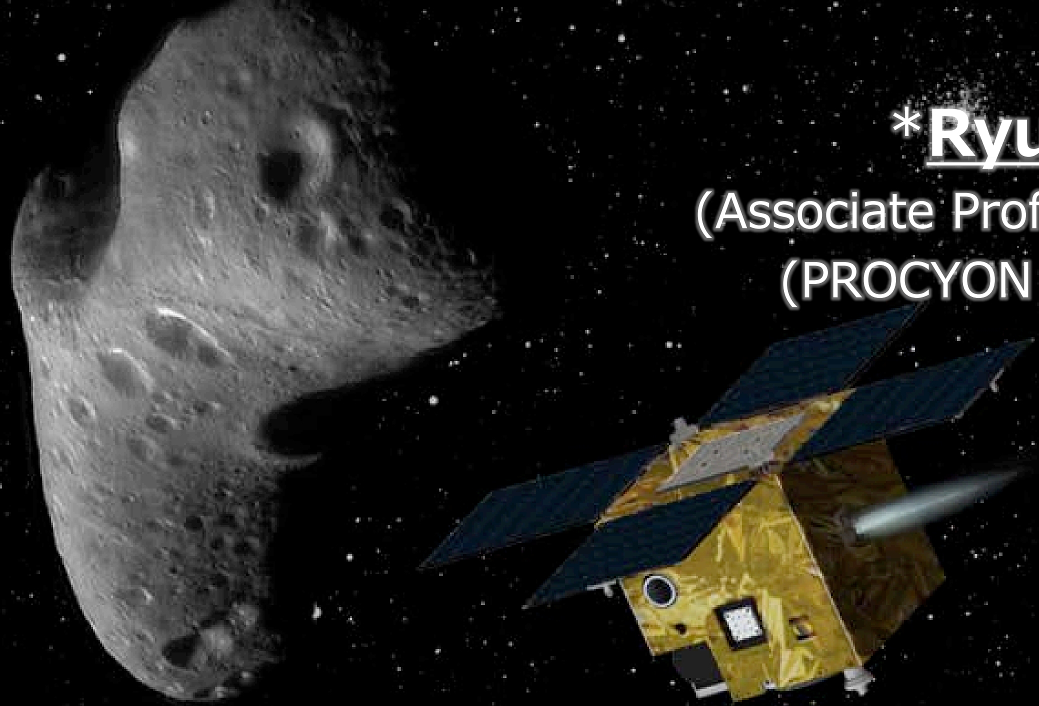
World's First Deep Space Exploration Micro-Satellite PROCYON

- my experience from CanSat to deep space mission -

*Ryu FUNASE
(Associate Professor, Univ. of Tokyo)
(PROCYON project manager)

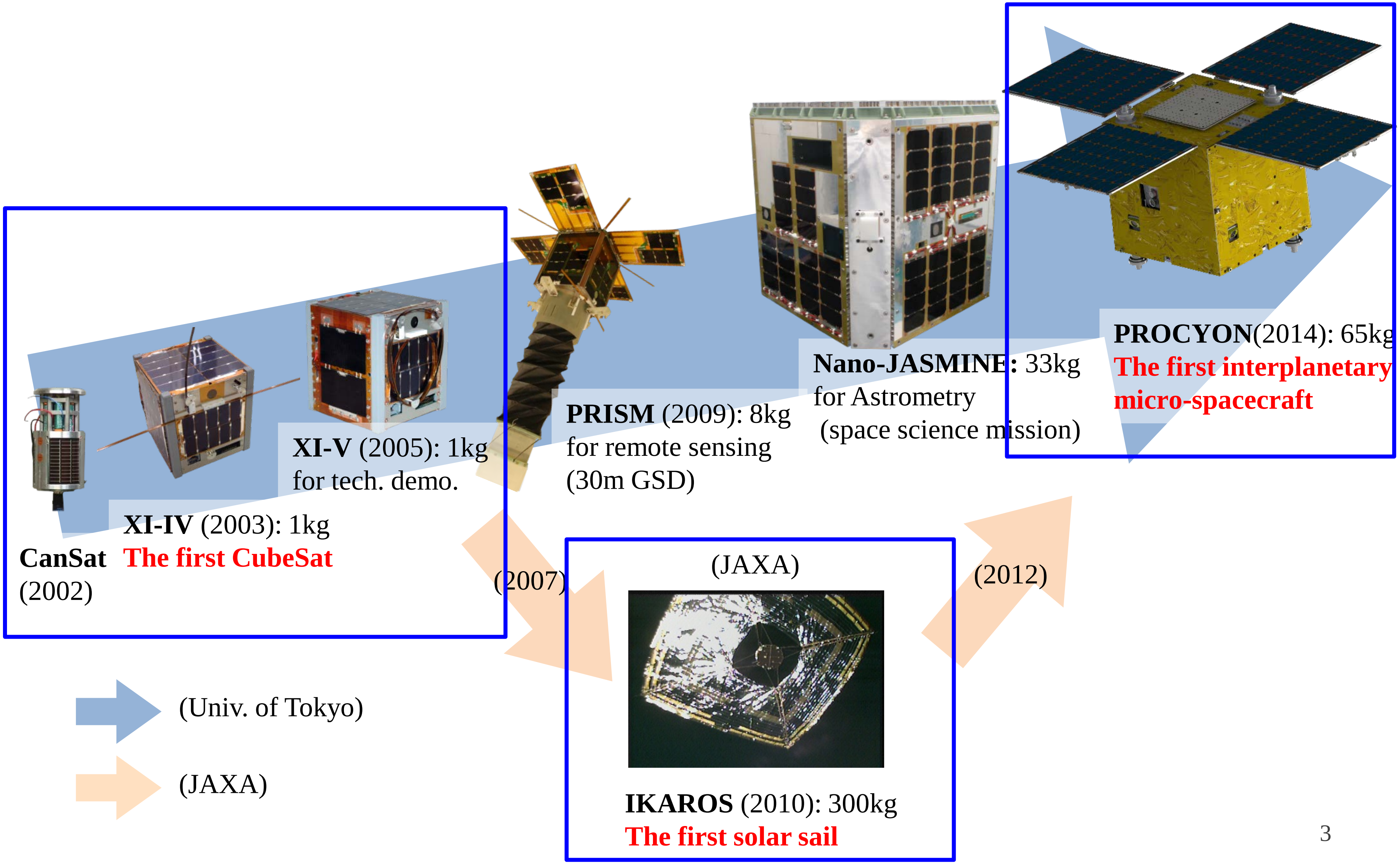


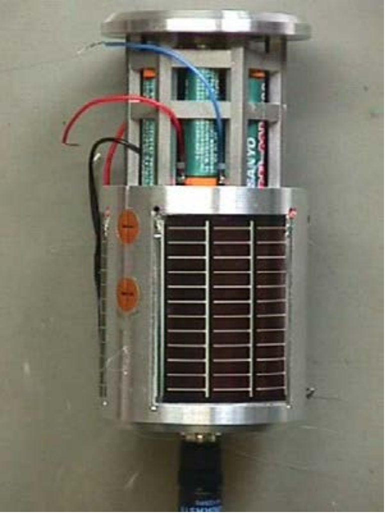
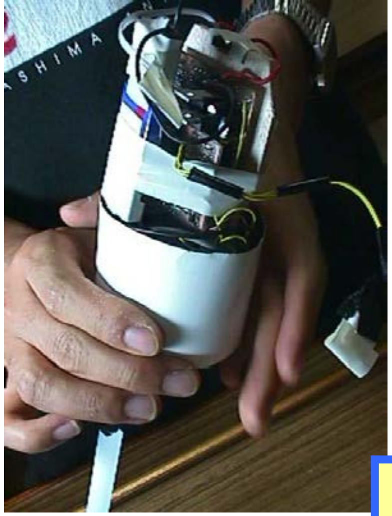
2015.07.03 3rd UNISEC-Global Meeting

Outline

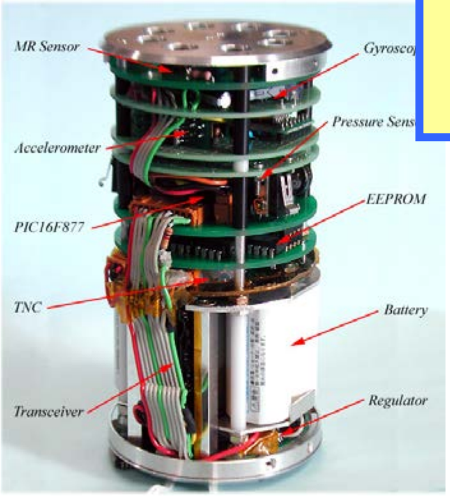
- My experience on nano, micro, small satellites
  - CanSat
  - CubeSat
  - Small (large?) deep space mission at JAXA
  - Deep space micro-satellite (PROCYON)
- PROCYON
  - Mission, spacecraft design, achievements
  - Future prospects of deep space mission by small satellites
- Conclusion

My small satellite experiences at Univ. of Tokyo and JAXA

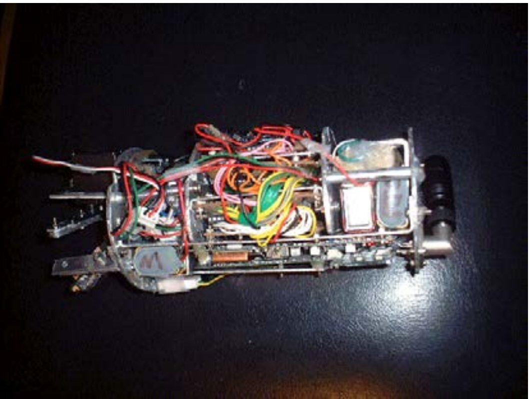


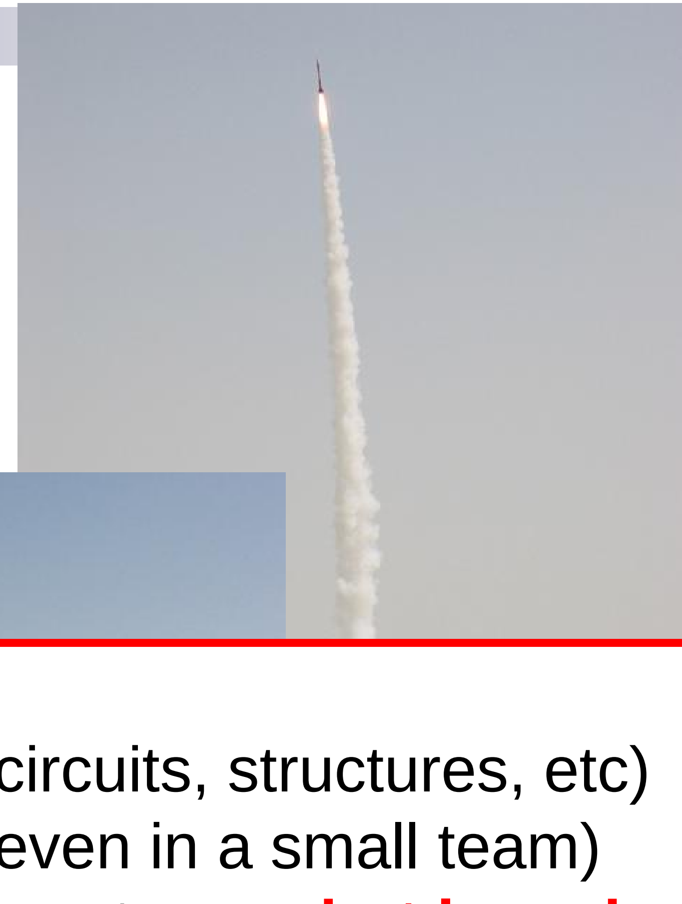



Starting Point: CanSat (2002)







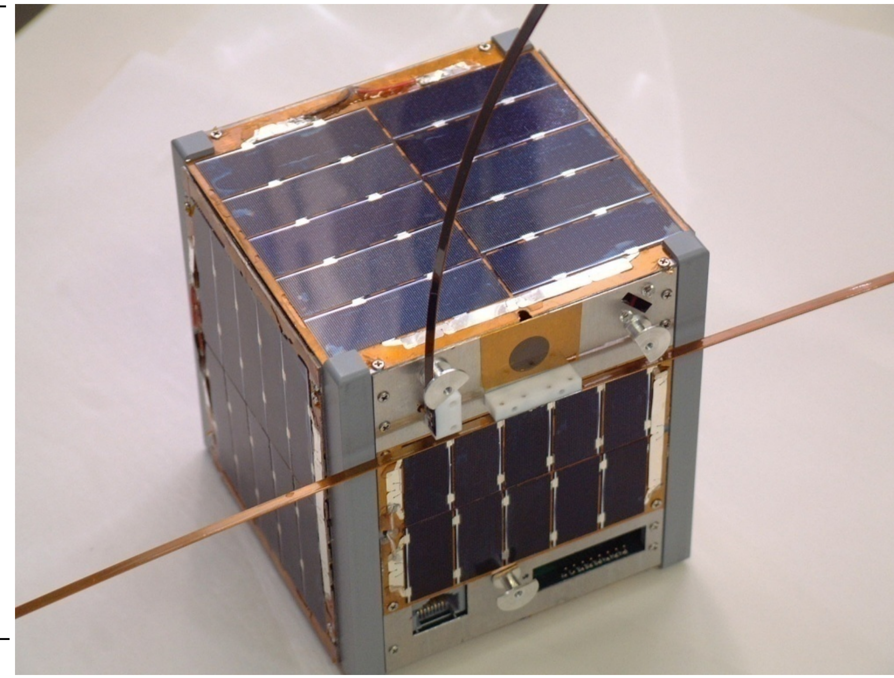
What I learned from CanSat project:

- ABC of **making things** (electronic circuits, structures, etc)
- (difficulty of) project management (even in a small team)
- (difficulty of) making mission success at **one-shot launch**
    - **Most essential part of space missions**

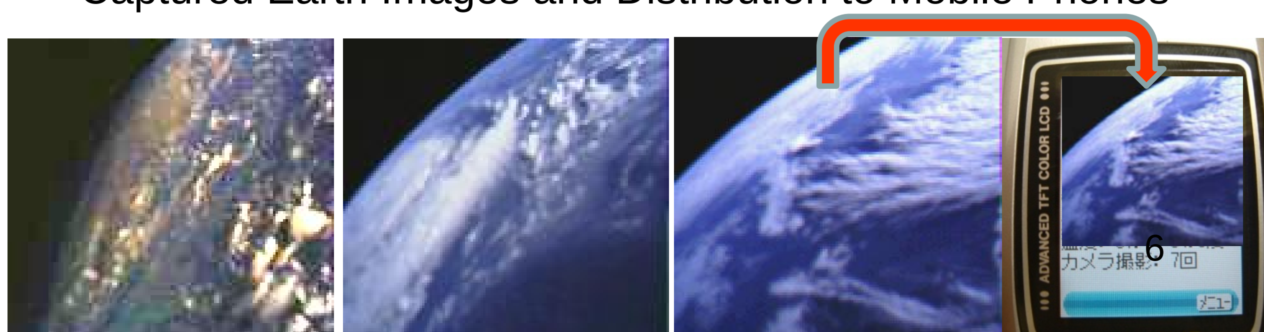
The first CubeSat “XI-IV (Sai Four)”

Mission: **Pico-satellite bus technology demonstration** , Camera experiment
Developer: University of Tokyo
Launch: ROCKOT (June 30, **2003**) in Multiple Payload Piggyback Launch

Size	**10x10x10[cm]** CubeSat
Weight	**1 [kg]**
Attitude control	Passive stabilization with permanent magnet and damper
OBC	PIC16F877 x 3
Communication	VHF/UHF (max 1200bps) amateur frequency band
Power	Si solar cells for 1.1 W
Camera	640 x 480 CMOS
Mission life	more than 8 years



Captured Earth Images and Distribution to Mobile Phones

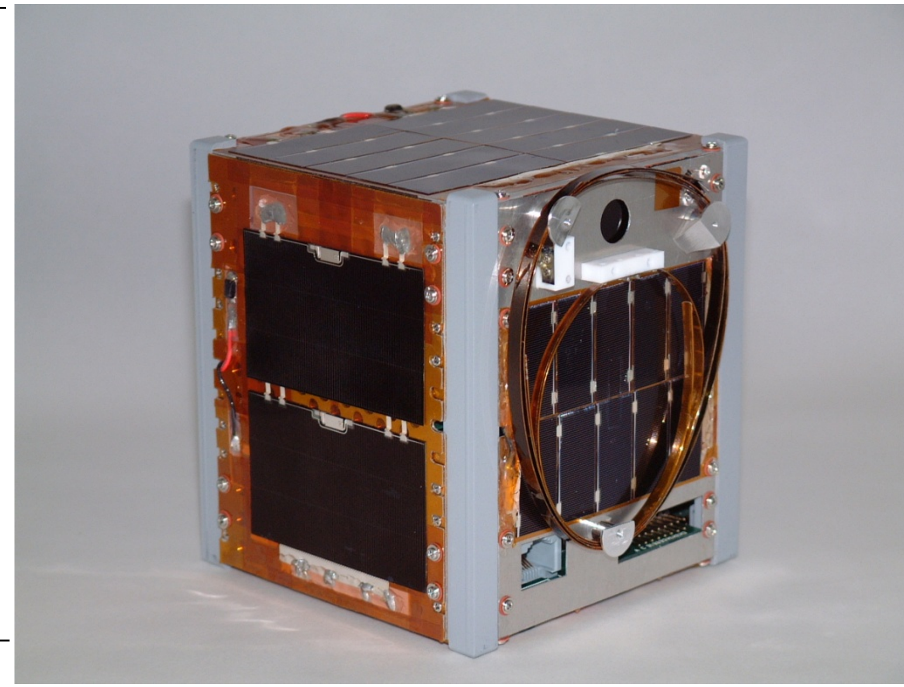


CubeSat “XI-V (Sai Five)”

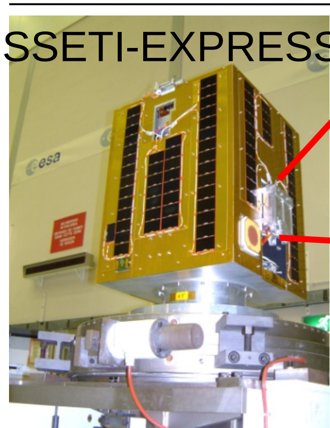
Intelligent Space Systems Laboratory
University of Tokyo
ISSL

Mission: **CIGS solar cell demonstration**, Advanced camera experiment
Developer: University of Tokyo
Launch: COSMOS (October 27, **2005**) deployed from “SSETI-EXPRESS”

Size	10x10x10[cm] CubeSat
Weight	1 [kg]
Attitude control	Passive stabilization with permanent magnet and damper
OBC	PIC16F877 x 3
Communication	VHF/UHF (max 1200bps) amateur frequency band
Power	Si, GaAs, **CIGS cells**
Camera	640 x 480 CMOS
Mission life	> 5 years



SSETI-EXPRESS

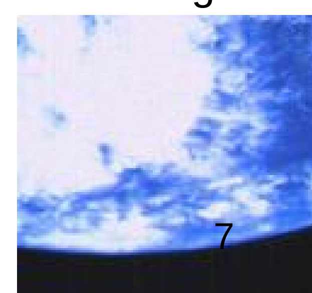


T-POD deployment System

Deployed from SSETI-EXPRESS in space

JAXA/NEDO CIGS Solar Cells

Captured Earth Images



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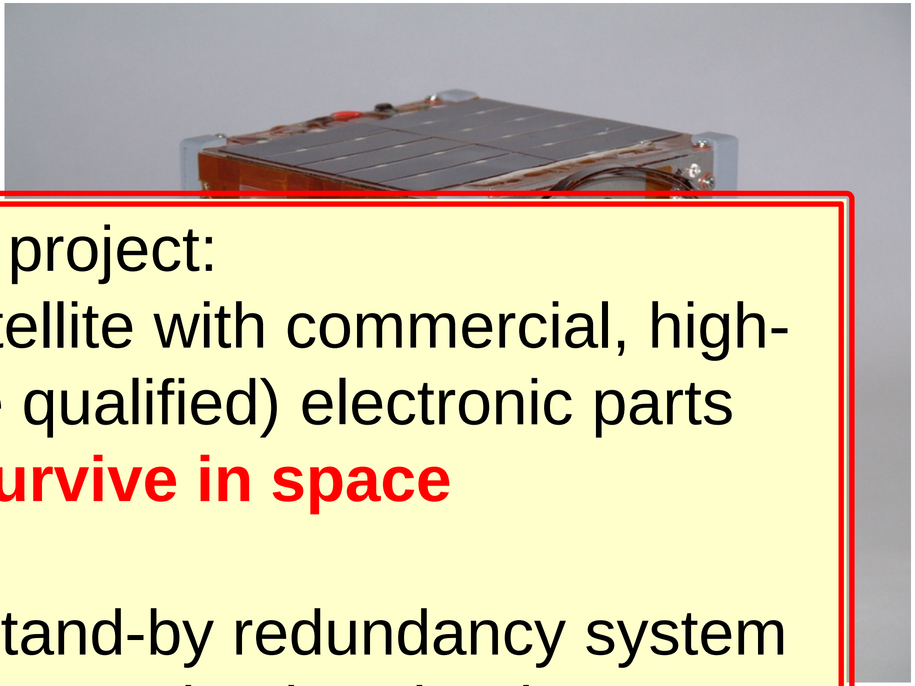
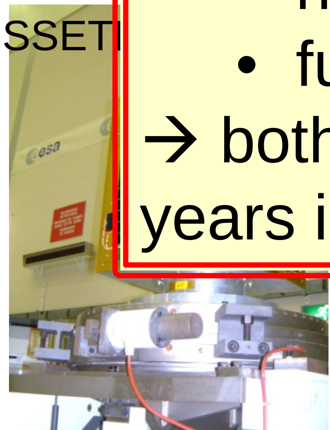
SSETI



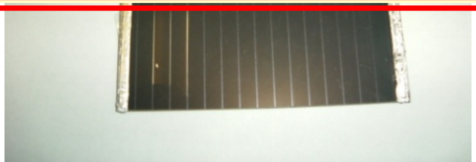
What I learned from CubeSat project:

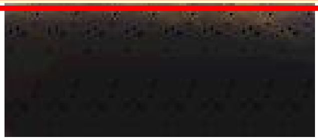
- How to make very small satellite with commercial, high-performance (but not space qualified) electronic parts
- How to make the satellite **survive in space environments**
  - not by applying simple stand-by redundancy system
  - functional redundancy, cross-check redundancy

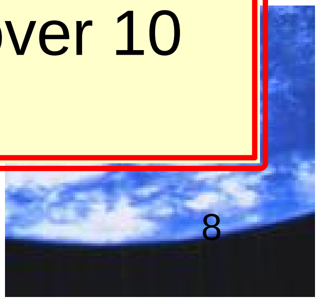
→ both XI-IV and XI-V are **now still operational** over 10 years in orbit



Deployed from SSETI-EXPRESS in space



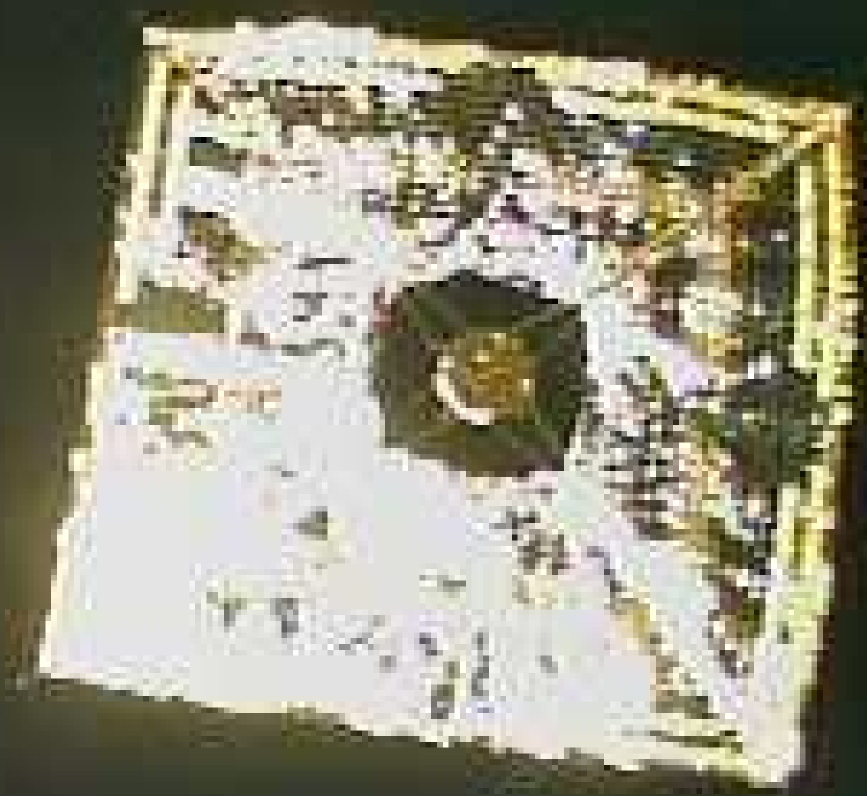




Deep Space Solar Power Sail Demonstrator

IKAROS

Interplanetary Kite-craft Accelerated by Radiation Of the Sun



Type: Spin type solar sail
Sail Size: 14m x 14m
S/C Weight: **307kg**
Orbit: Venus Transfer

Launch: May 21, 2010
Sail Deployment: June 9, 2010

Deep Space Solar Power Sail Demonstrator

IKAROS

Interpla
Radiati

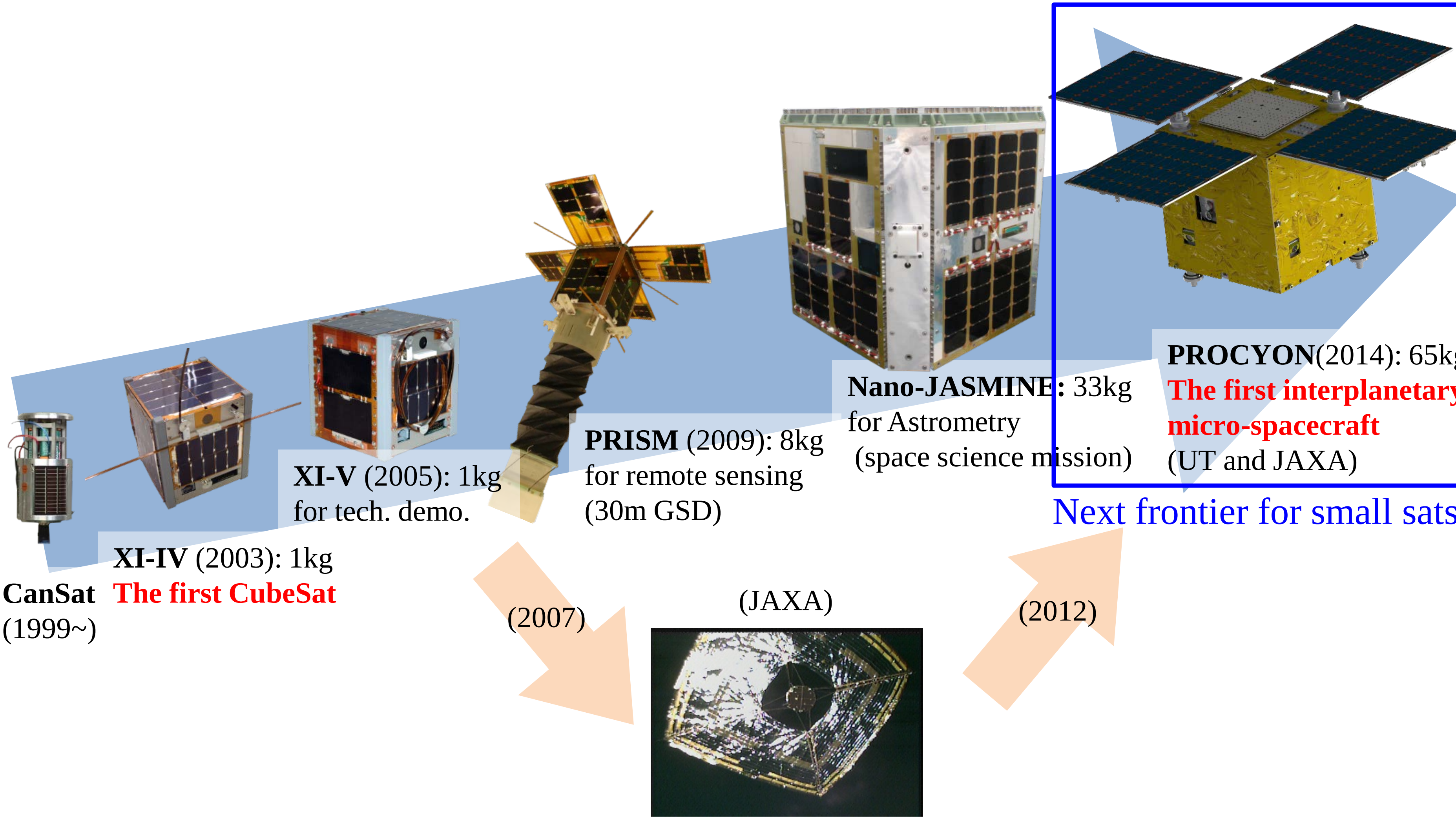
A lot of things I learned from IKAROS project:

- Conservative way to **assure reliability in a large mission** by national agency (JAXA)
  - opposite from "CubeSat" way of mission assurance
  - but, is certainly valid for this large mission…
  - The **"optimal" way of assuring mission success** depends on the size/cost of the spacecraft
- How to make a spacecraft to **operate in deep space**
  - Certainly different from the Earth-orbiting satellite
  - difficult, but **not too difficult** once we know how
  - Small satellites can go to deep space…??

Type:
Sail S
S/C V
Orbit:

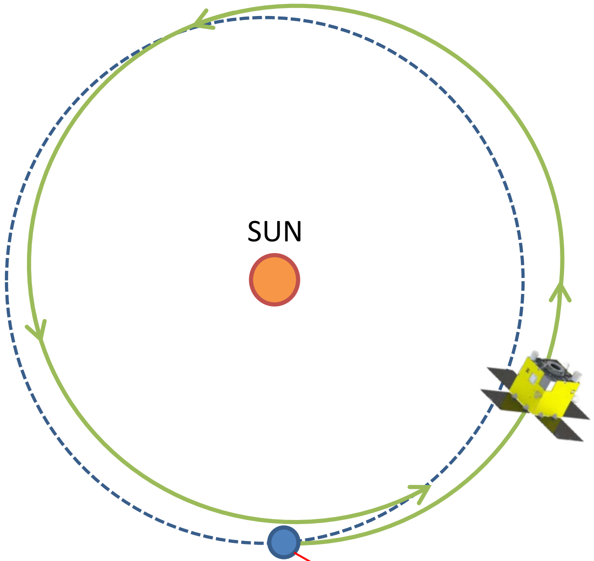
Launch: May 21, 2010
Sail Deployment: June 9, 2010

My small satellite experiences at Univ. of Tokyo and JAXA



Primary Mission

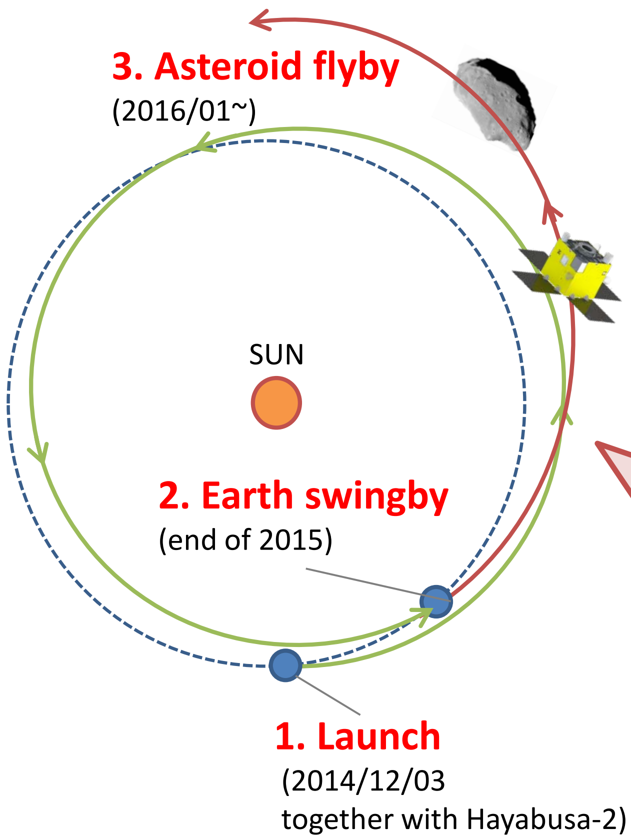
Demonstration of micro-spacecraft bus system for deep space exploration (requires 2~3 months)



- **Power** generation/management (>240W)
- **Thermal** design (to accommodate wide range of Solar distance (0.9~1.5AU) and power consumption mode (IES on/off))
- **Attitude** control (3-axis, 0.01deg stability)
- **Deep space communication & navigation**
  - High efficiency (GaN SSPA, >30%)
  - High output (>15 W)
  - Precise nav by novel "Chirp DDOR"
- **Deep space micro propulsion system**
  - RCS for attitude control/momentum management (8 thrusters)
  - Ion propulsion system for trajectory control (1 axis, Isp=1000s, thrust=300uN, overall ΔV=400m/s)

Secondary Mission (optional/advanced)

Engineering/Scientific mission to advance/utilize deep space exploration (~L+1.5yr)



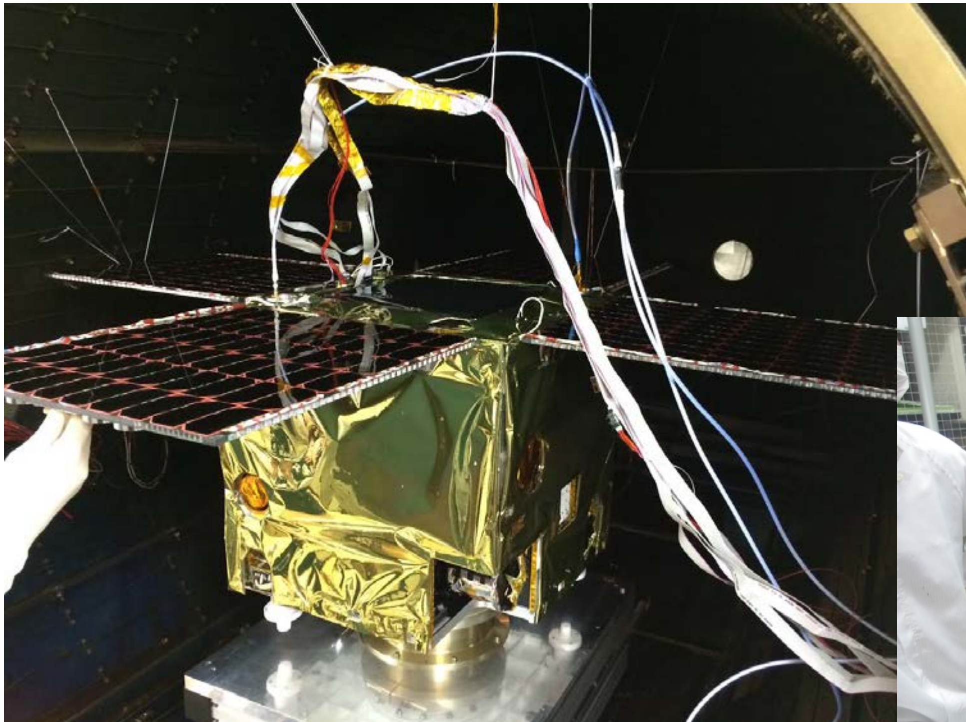
[engineering mission]

1. **Deep space maneuver** to perform Earth swingby and trajectory change to target an asteroid flyby
2. **High-res observation of an asteroid during close (<30km) and fast (~10km/s) flyby**
   - Optical navigation and guidance to an asteroid
   - Automatic Line-of-sight image-feedback control to track asteroid direction during close flyby

[scientific mission]

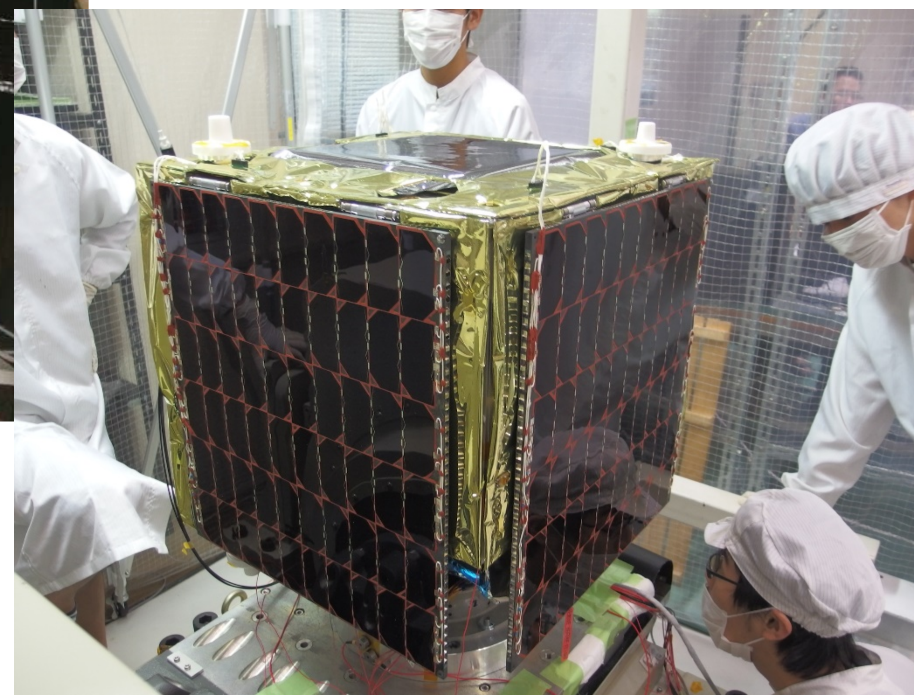
1. **Wide-view observation of geocorona** with **Lyα imager** from a vantage point outside of the Earth's geocorona distribution

External View of PROCYON

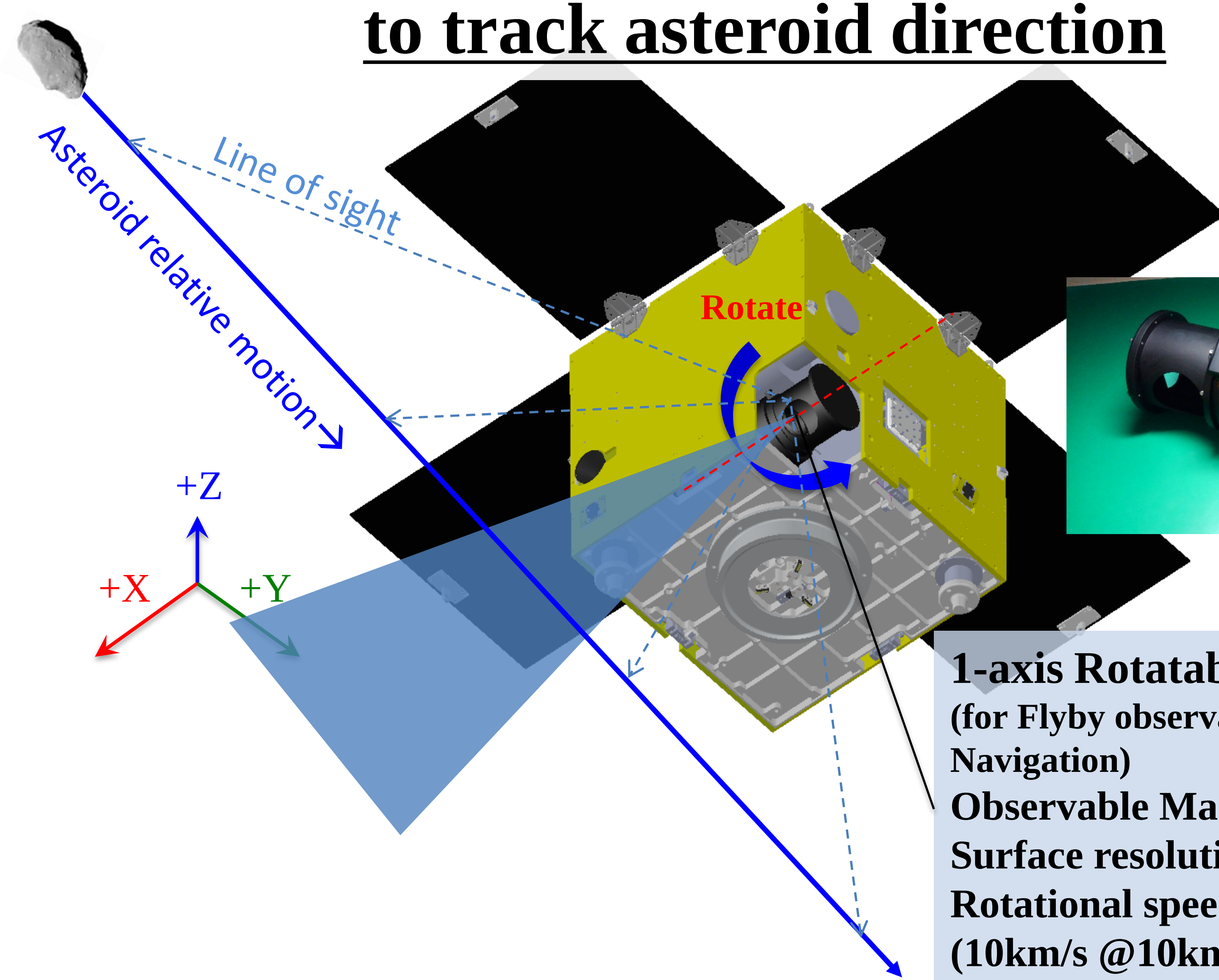


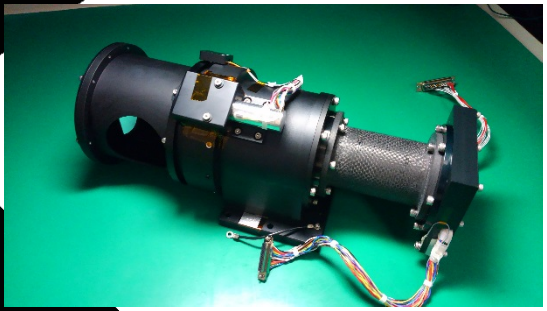
(SAP deployed)

(SAP folded)



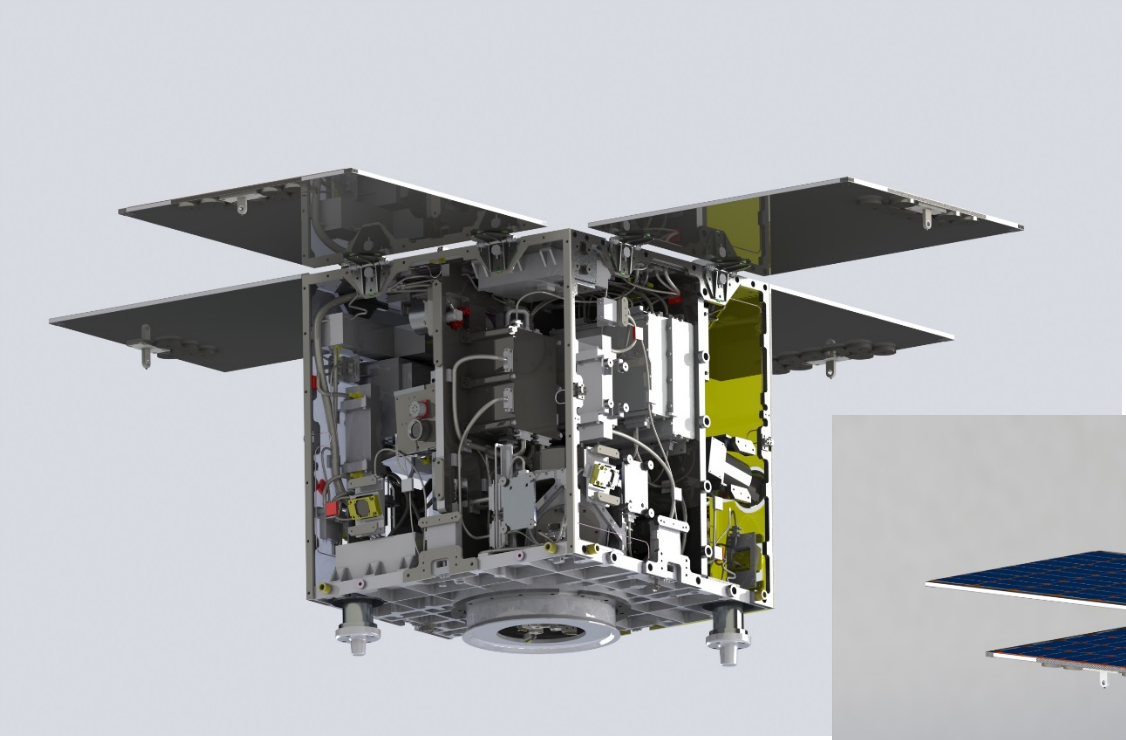
Real-time Line-of-sight image-feedback control to track asteroid direction

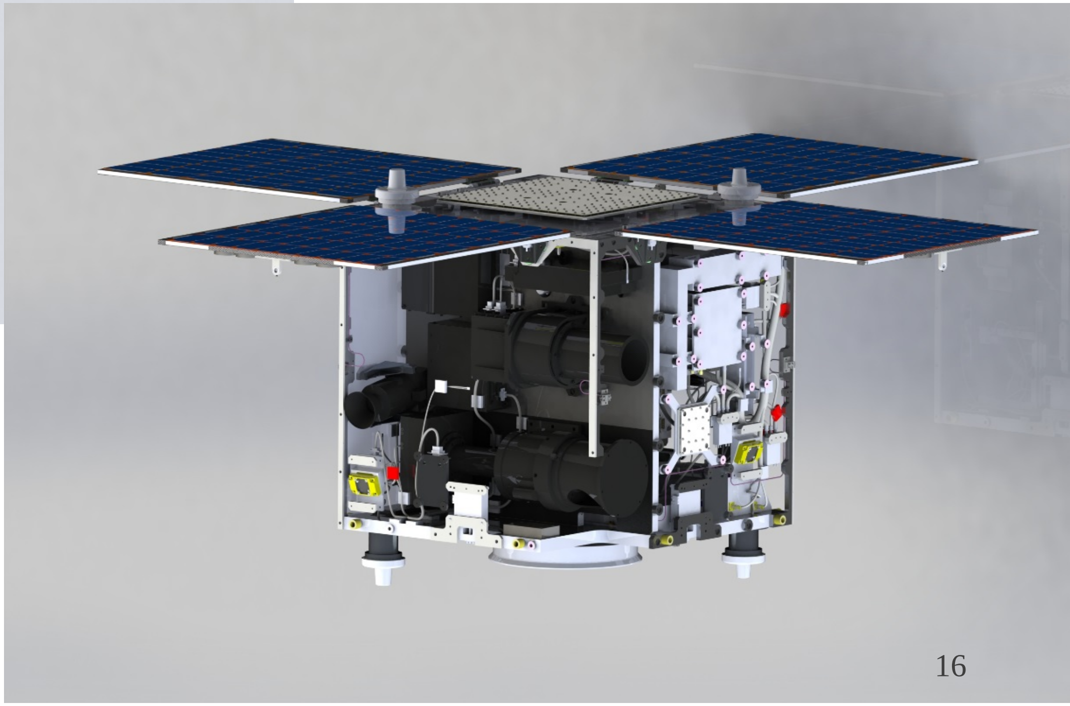




1-axis Rotatable Telescope
(for Flyby observation and Optical Navigation)
Observable Magnitude: 12
Surface resolution: ~1[m]@10km
Rotational speed: <55[deg/s]
(10km/s @10km)

Internal View of PROCYON





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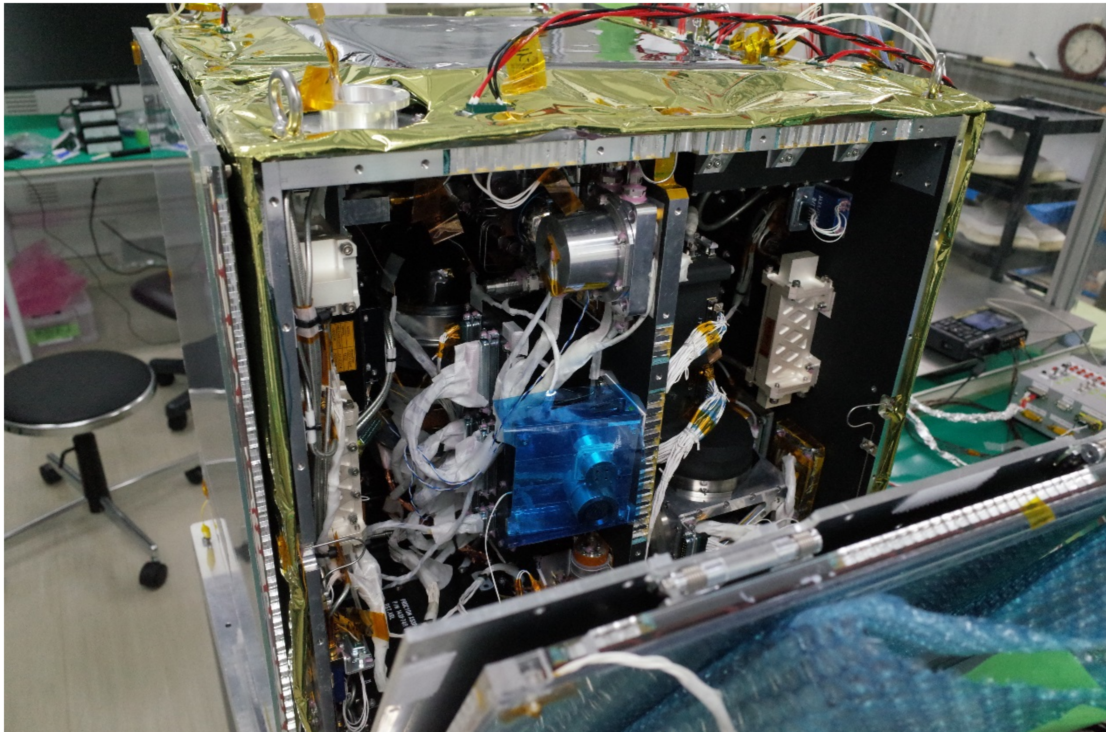
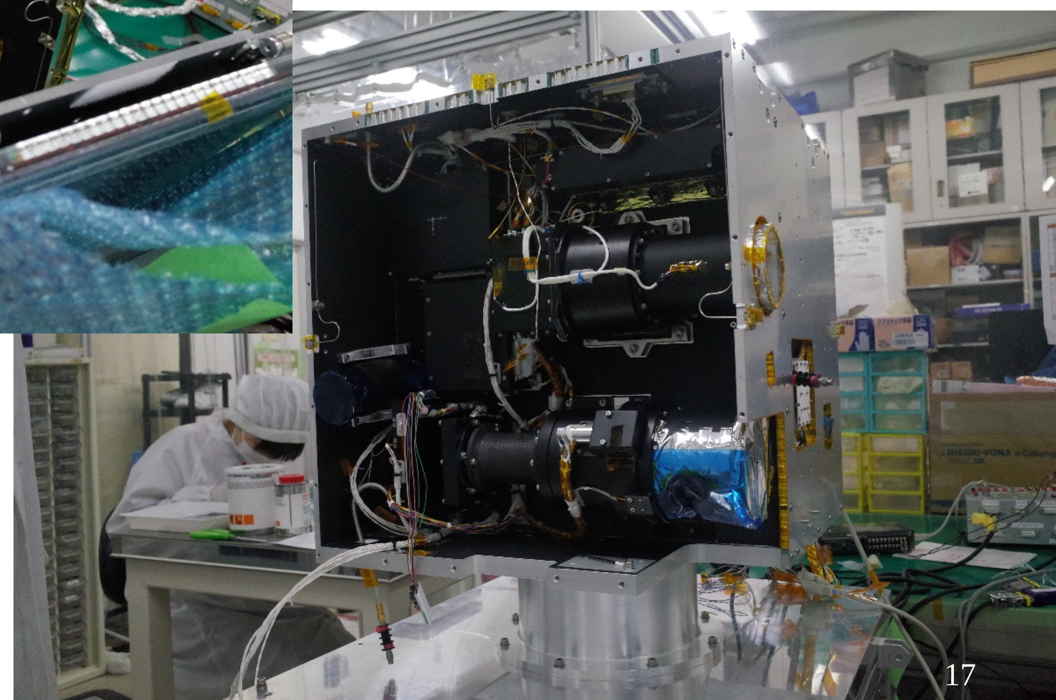
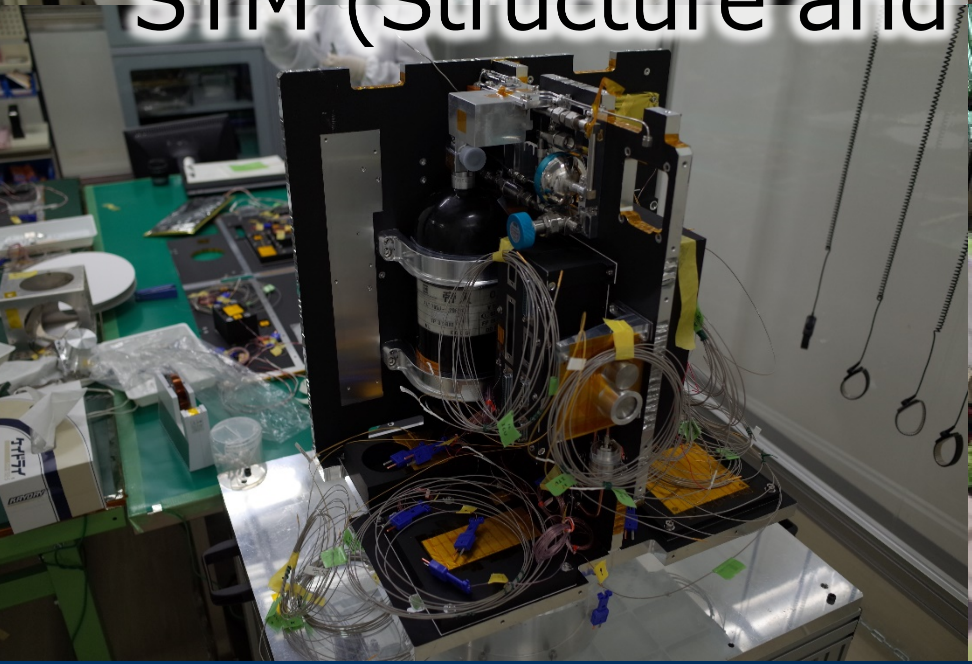
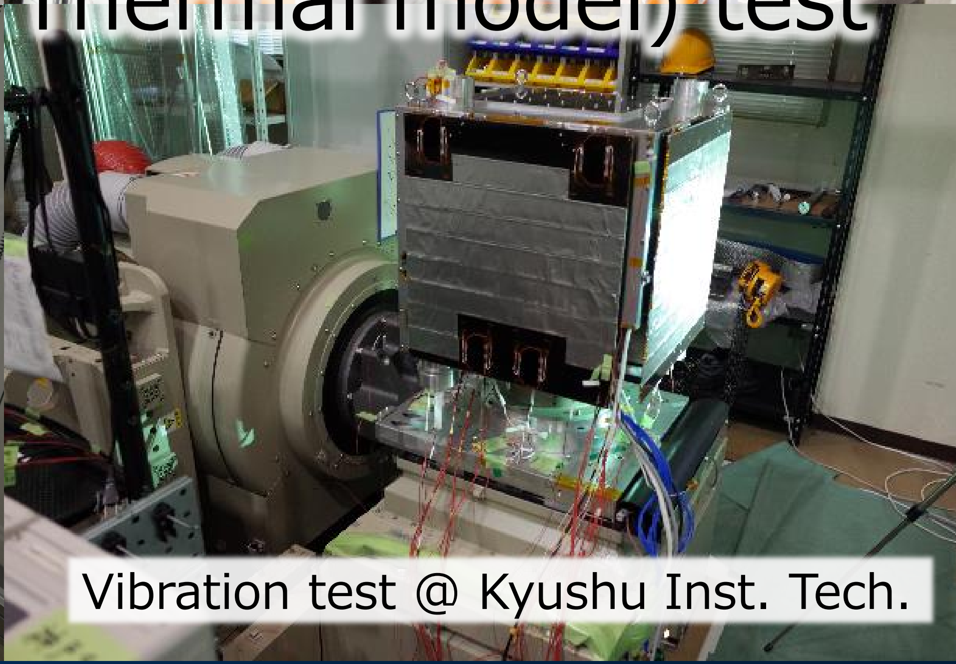


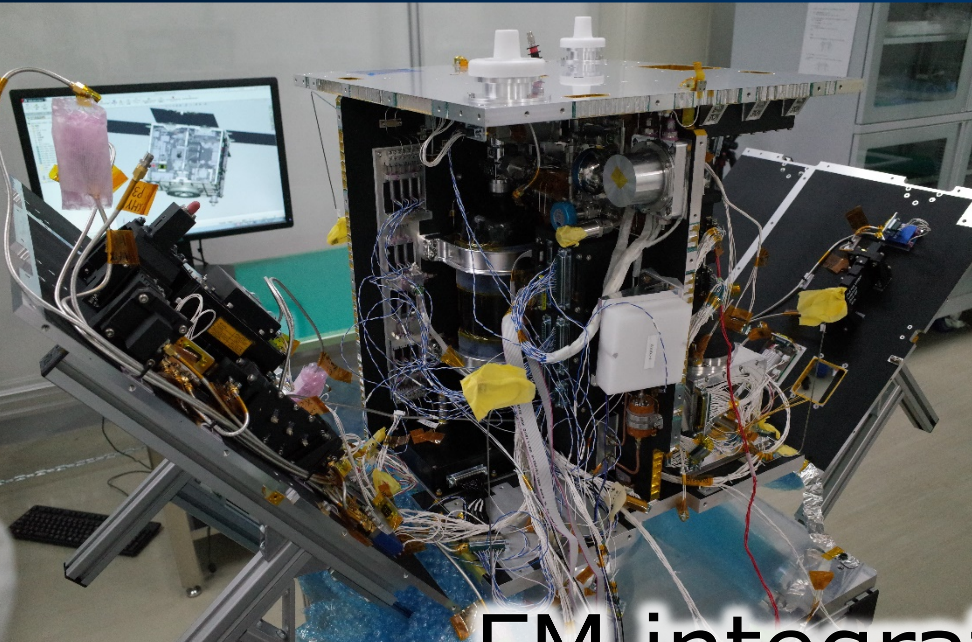
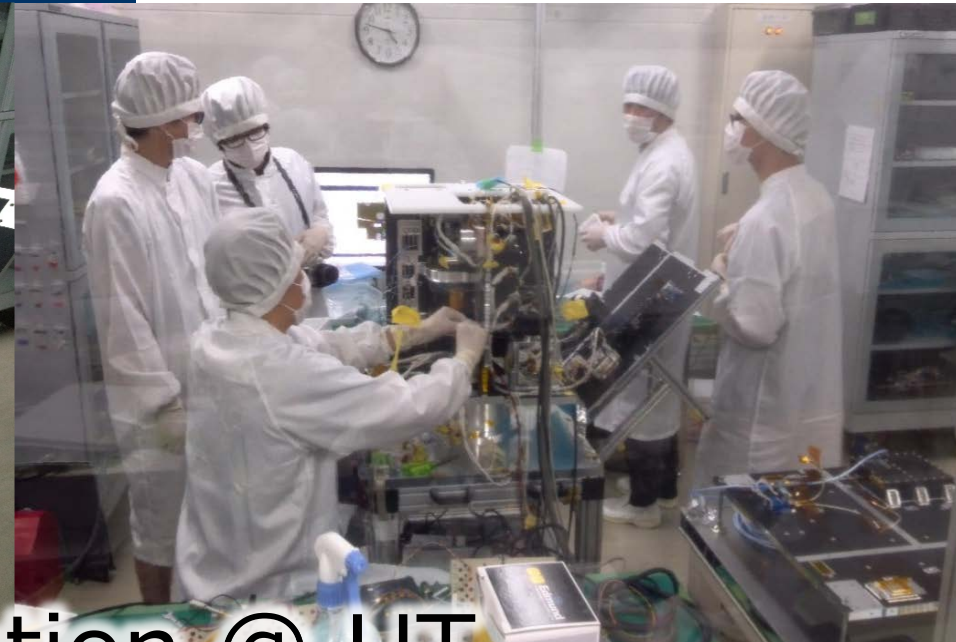
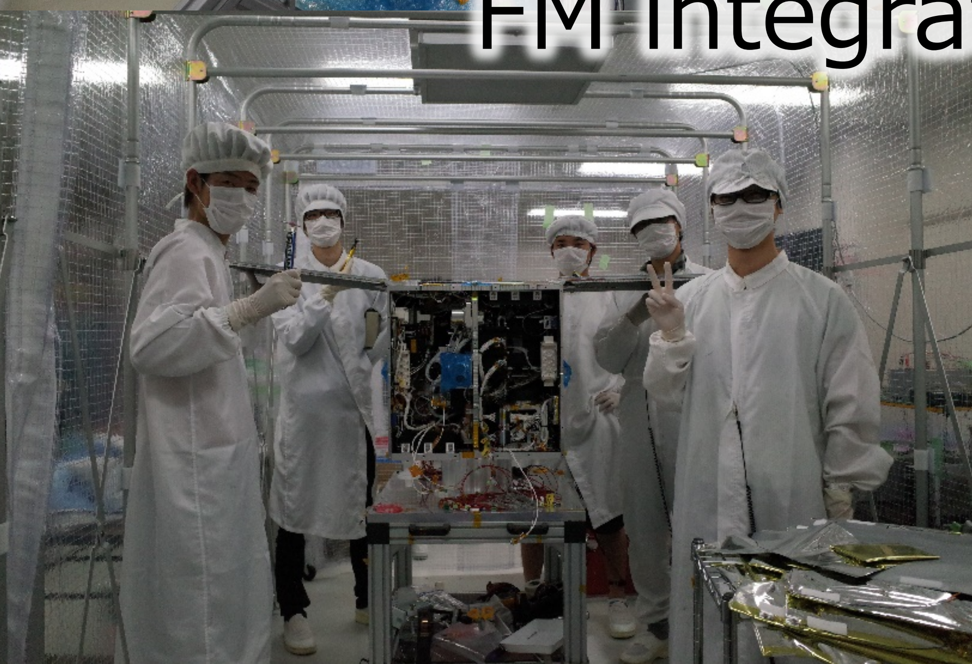


STM (Structure and Thermal model) test

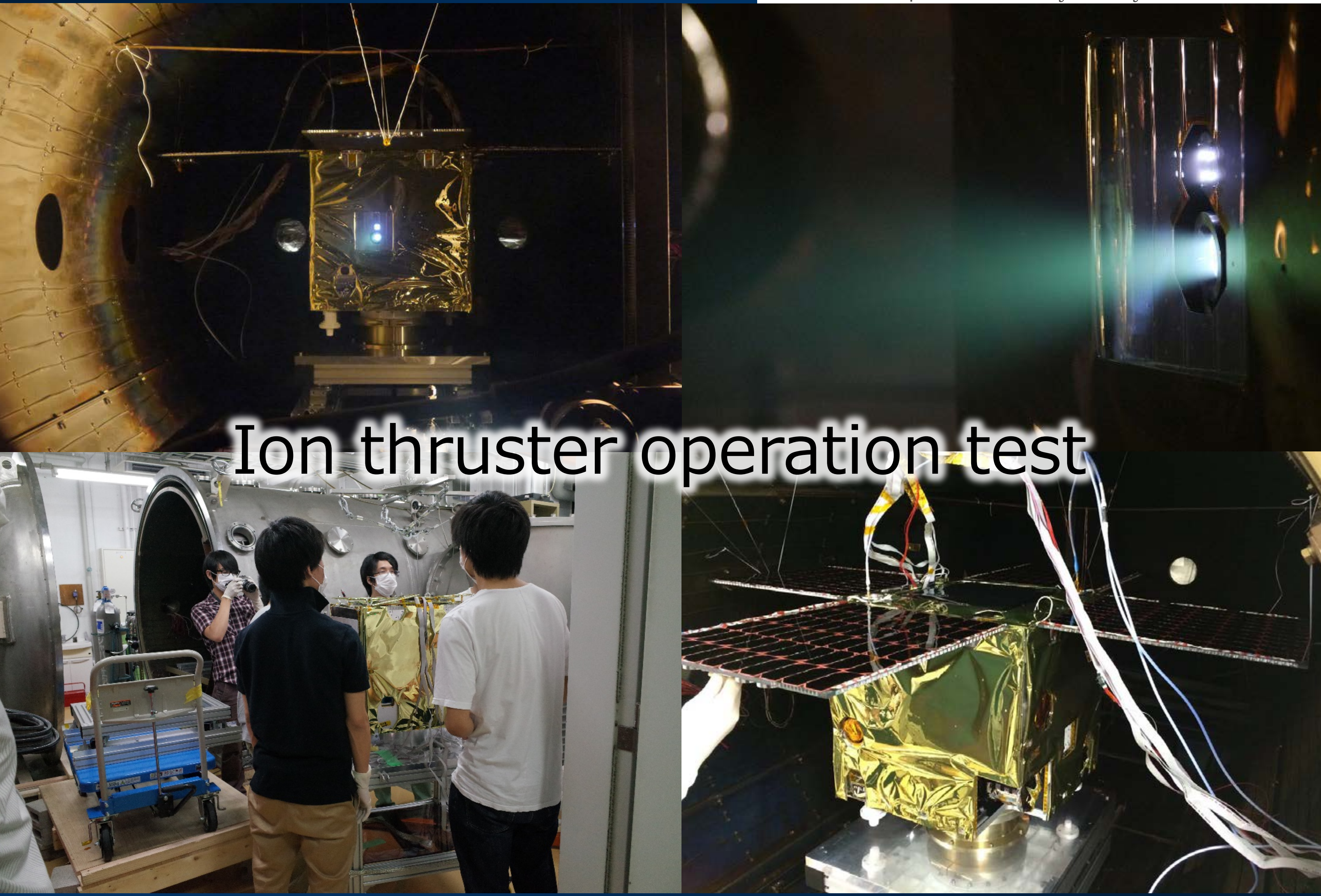




FM integration @ UT

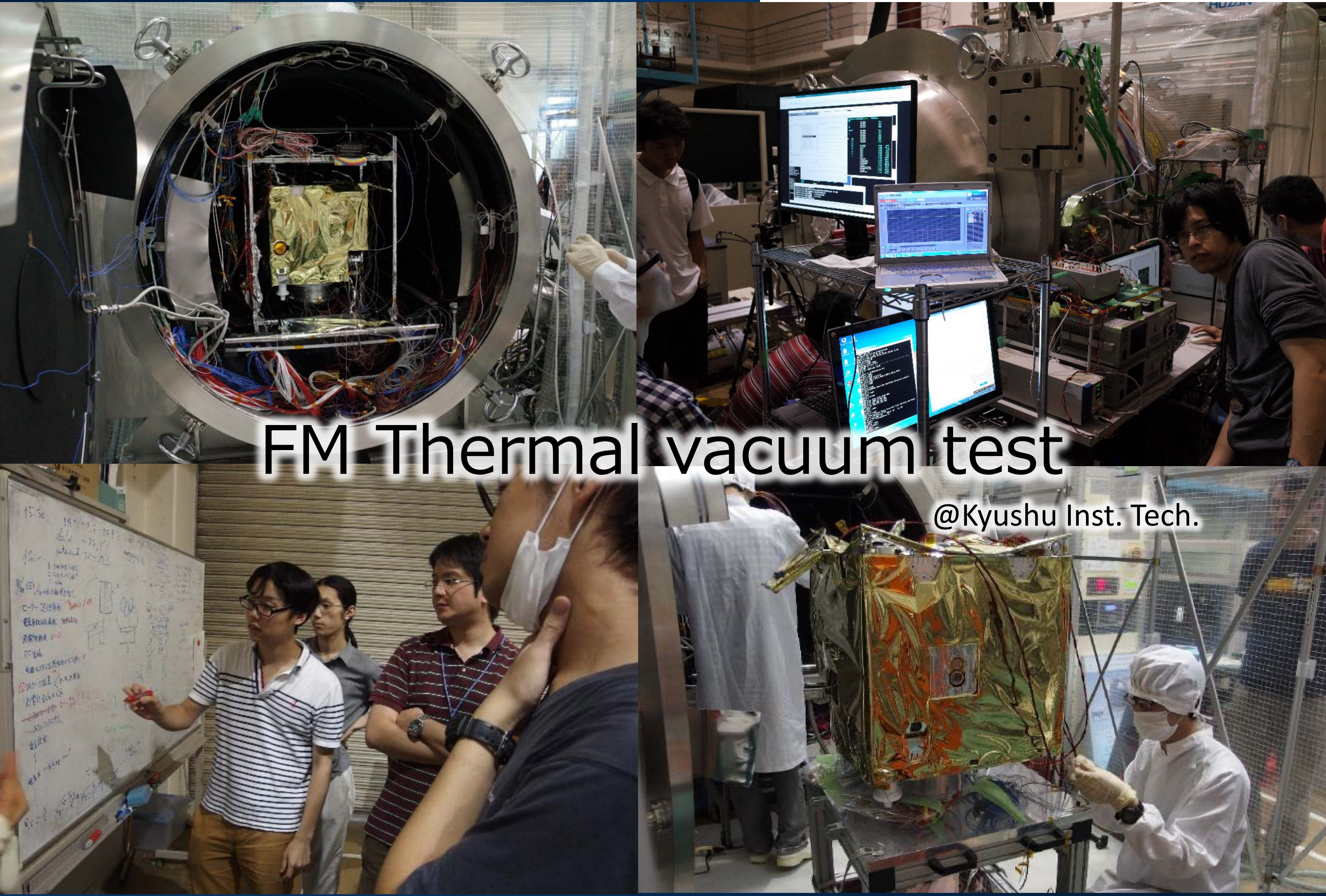





Ion thruster operation test



FM Thermal vacuum test

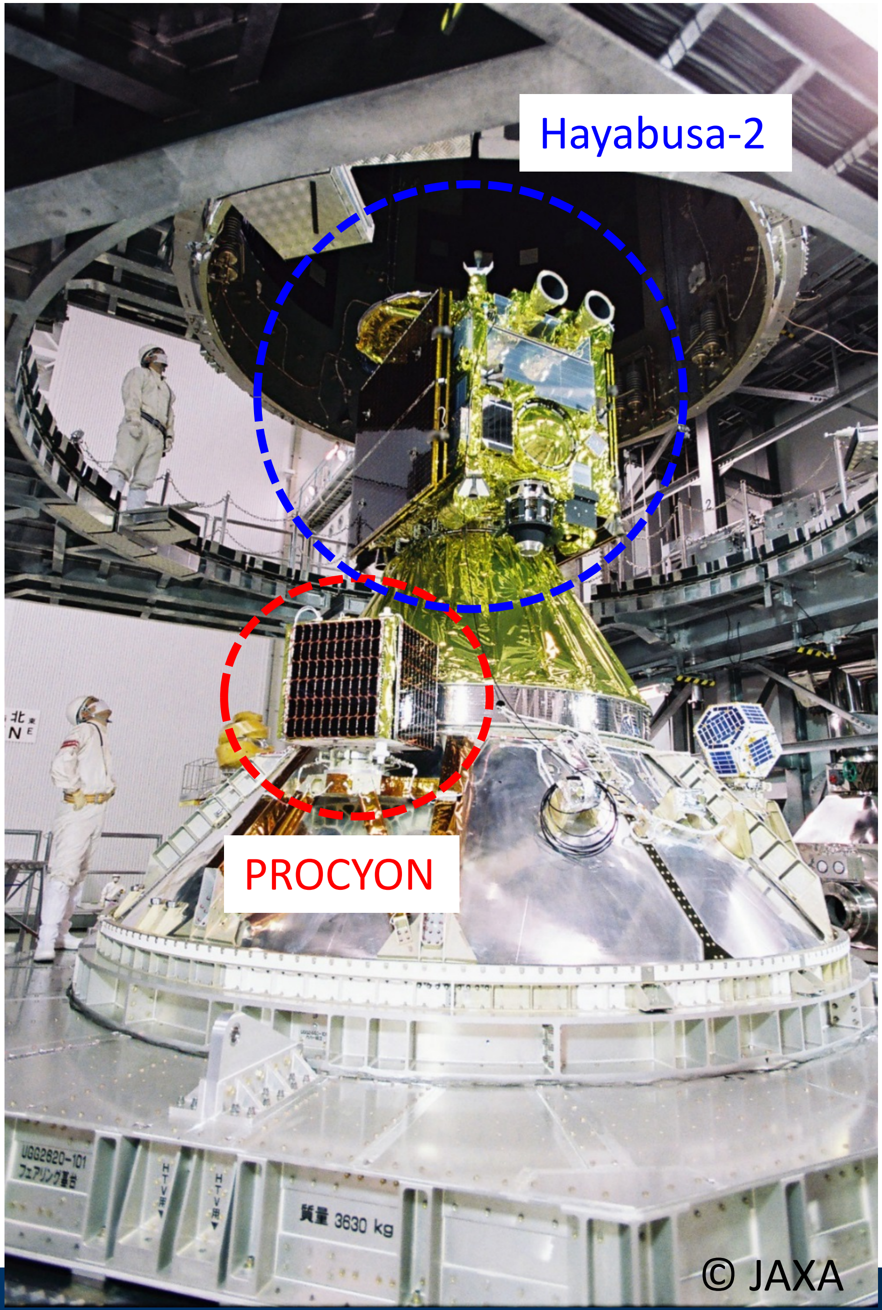
@Kyushu Inst. Tech.



FM vibration test/shock test

Vibration test@Kyushu

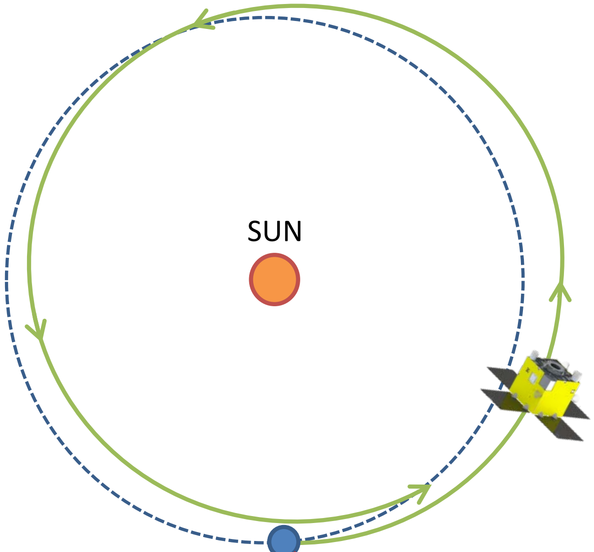
Separation shock test@JAXA


Hayabusa-2
PROCYON
質量 3630 kg
© JAXA


H-IIA rocket
NIPPON
© JAXA

Primary mission results

Demonstration of micro-spacecraft bus system for deep space exploration (requires 2~3 months)



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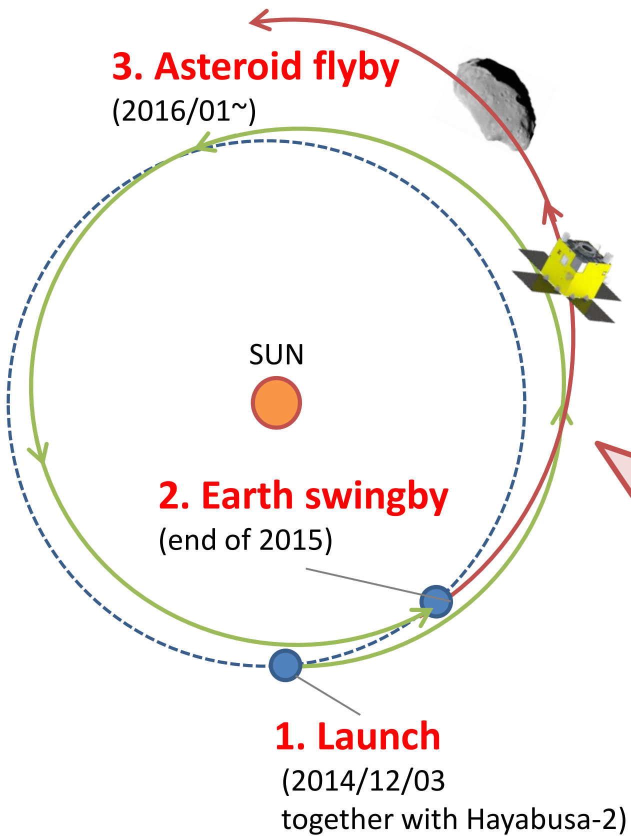

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- Automatic Line-of-sight image-feedback control to track asteroid direction during flyby

[scientific mission]

✓ **Wide-view observation of geocorona** with **Lyα imager** from a vantage point outside of the Earth's geocorona distribution

Mission status

- **Demonstration of deep space bus system**
  → success!
- **Scientific mission** (geocorona observation)
  → success!
- All the mission were successful excluding **the <u>long-time</u> deep space maneuver** and the subsequent **asteroid flyby**.

- demonstrated the capability of this class of spacecraft to conduct deep space mission by itself and it can be a useful tool of deep space exploration.

Future perspective of PROCYON-type small deep space missions

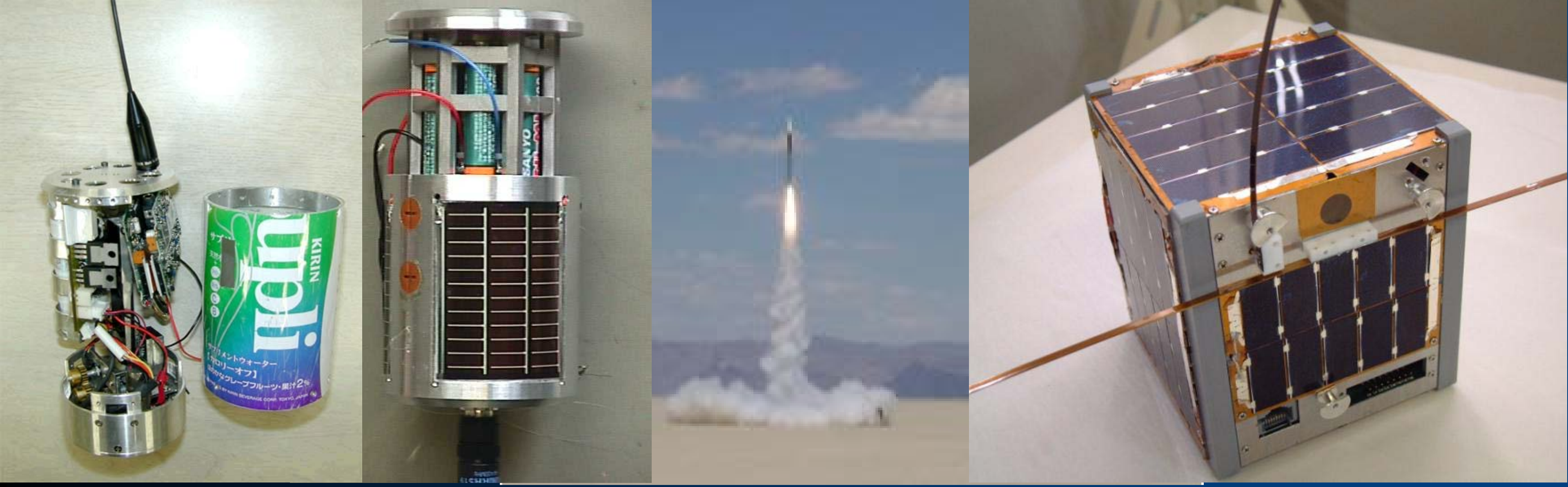
- **Possible missions by micro spacecraft (applications)**
  - **precursor** to a larger mission (e.g. Human planetary exploration, asteroid mining, etc)
  - **small-scale** mission for **"focused" science** with limited instruments
- **Trajectory/Launch options**
  "Don't miss any chance to ride" by taking advantage of its short development time and flexibility to catch a wide variety of launch opportunity in the world
  - **Piggyback (direct Earth escape) + Earth swingby + small Delta-V**
    → flexible target selection (asteroid/comets/planets) via Earth-swingby
  - **Piggyback (Lunar mission, LTO) + Lunar swingby + small Delta-V**

Concluding remarks

- From my experience, I believe that the **"CubeSat" way of building satellites can open a new door of space development and space exploration**
  - Boldly (and carefully at the same time) introduce novel technology
  - Take risks and do "the first" challenging mission
  - **The rapid mission cycles will create innovation**

- CanSat is the best first step towards space

- Explore our own (original) frontier, and let's make a new world of space exploration!



Challenging new space frontier by small satelltes

Intelligent Space Systems Laboratory, Univ. of Tokyo