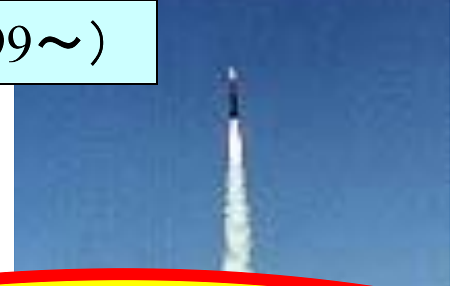


CanSat & Rocket Experiment('99～)

Hodoyoshi-1 '14

Possibilities and Future Vision of Micro/nano/pico-satellites - From Japanese Experiences

Shinichi Nakasuka
University of Tokyo

CubeSat 03,05

PRISM '09

Nano-JASMINE '15

Contents

- Features of Micro/nano/pico-satellites
- Japanese History and Lessons Learned
  - CanSat to CubeSat “First CubeSat on orbit”
  - From education to practical applications
  - Important tips for development
- Visions on Various Applications of Micro/nano/pico-satellites
- University Space Engineering Consortium (UNISEC) and International Collaborations

Micro/nano/pico-satellite

“Lean Satellite”

Micro-satellite: 20-100kg

Nano-satellite: 2-20kg

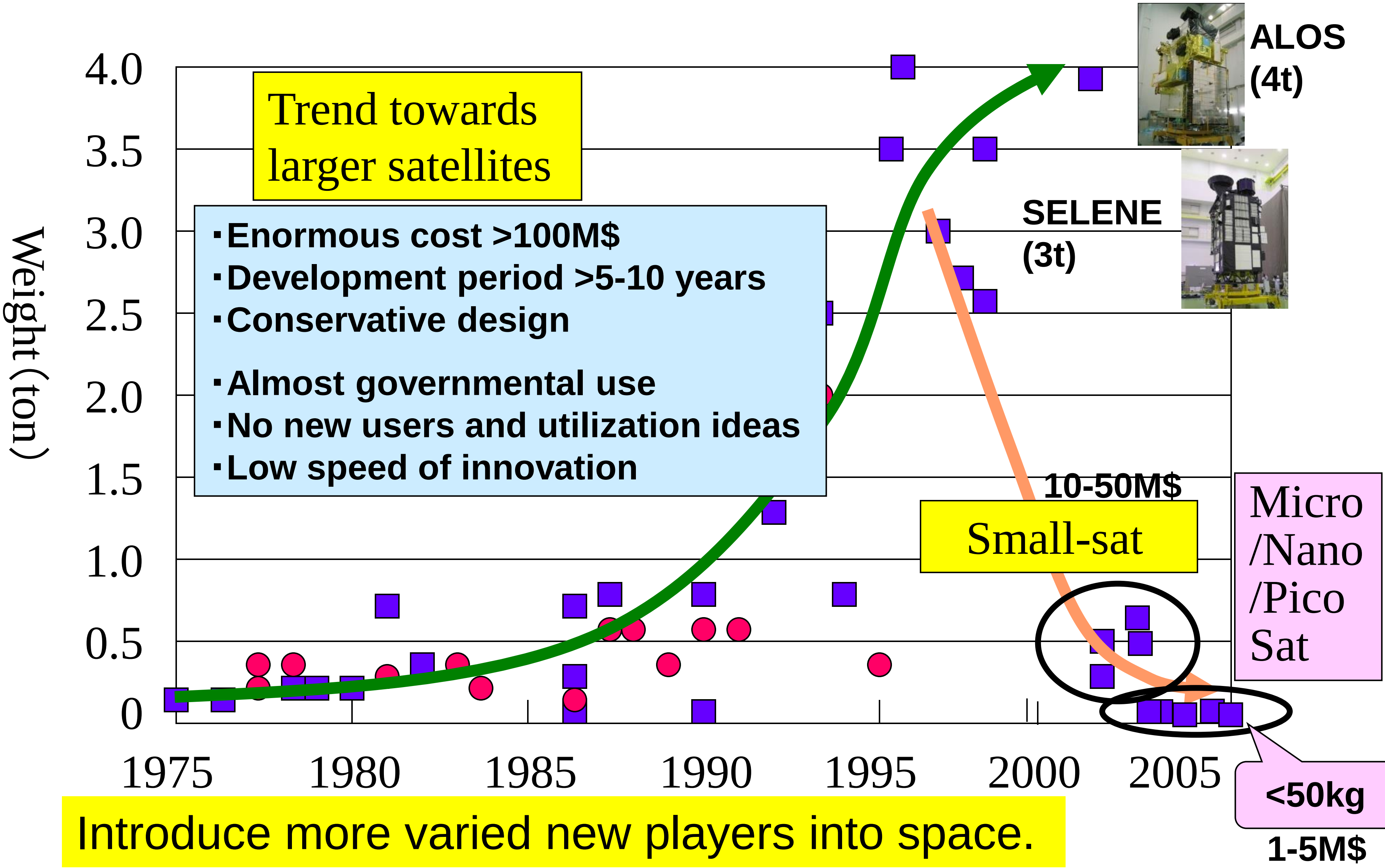
Pico-satellite: 0.5-2kg

Japanese Governmental Satellites

ALOS-1: 4 ton   ASNARO: 500 kg

Kaguya: 3 ton   Hayabusa: 510 kg

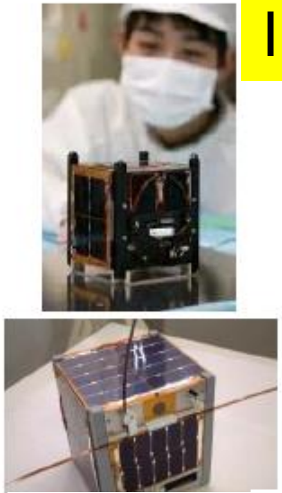
Motivation of Smaller Satellites
Current Problem of Mid-large Satellites



- Enormous cost >100M$
- Development period >5-10 years
- Conservative design
- Almost governmental use
- No new users and utilization ideas
- Low speed of innovation

Introduce more varied new players into space.

Innovation by Micro/nano/pico satellites (<100kg)



Education

OPUSAT(1U:1kg)

XI-IV(1U:1kg)

Remote sensing Telescope

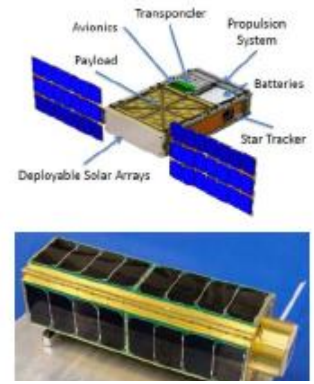
AeroCube(1.5U:2kg) AAReST

Dove,Flock(3U:4kg)

Weather

MiRaTA(3U)

MicroMAS(3U)



Bio-engineering

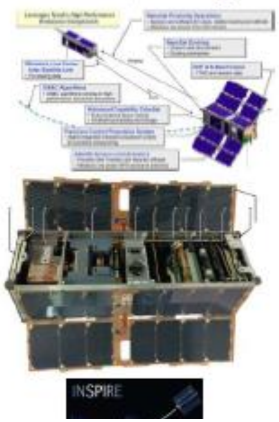
BioSentinel計画案(6U)

SPORESAT(3U:5.5kg)

Re-entry

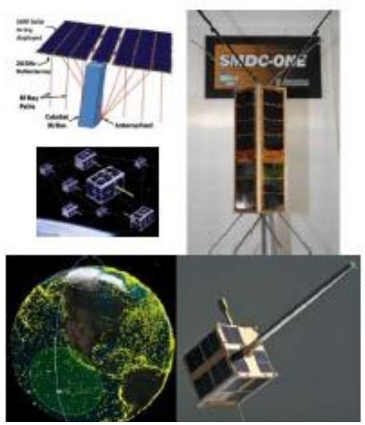
再突入回収(3U)

Sunjammer



Rendezvous/ docking

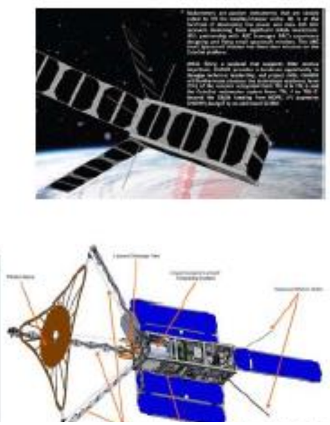
INSPIRE(3U)



Communication

高速通信・ISARA(3U)

低速通信・AISSAT-1(6kg)



Space Science

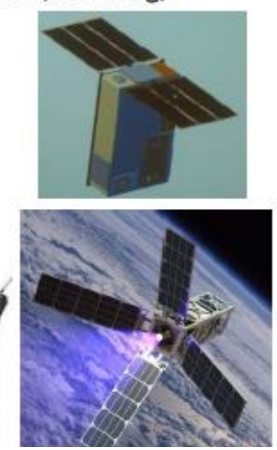
RACE(3U)

FS-7(3U)

Atmosphere

(可視・近赤外)

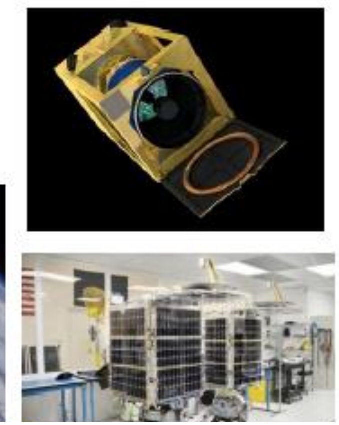
NEMO-AM(15kg)



Exploration

LWaDi(6U)

CAT(3U)



High Resolution.

SCOUT(50kg)

Skysat(120kg)

Universty/venture companies' innovative idea and development process

<10M$ < 2 years < 100kg, education, constellation of many satellites

Features of Micro/nano/pico-satellites

- VERY low cost (from >100M$ to <5M$)
  - Leads to new missions, business, sciences…
  - Introduce new users (companies, countries..)
  - Can be an educational tools
  - Can be very challenging
- Short life cycle (from >5 years to <1-2 years)
  - One cycle possible during university years
  - More iterations (from “project” to “program”)
  - Early return of investment (good for business)
- Simple and transparent satellite system
  - Easy to design, operate and trouble shoot
  - Each team member can see the total system

Educational Significances of Micro/Nano/Pico-Satellite and CanSat Projects

- ***Practical Training of Whole Cycle of Space Project***
  - Mission conceptualization, satellite design, fabrication, ground test, modification, launch and operation
  - Know what is important and what is not.
- ***Importance for Engineering Education***
  - Synthesis (not Analysis) of an really working system
  - Feedbacks from the real world to evaluate design, test, etc.
  - Learning from failures (while project cost is small)
- ***Education of Project Management***
  - Four Managements: "*Time, human resource, cost and risk*"
  - Team work, conflict resolution, discussion, documentation
  - International cooperation, negotiation, mutual understanding
- ***The effects were found more than expected !!***
- ***Also contribute to other technological areas !!***

University Satellites in Japan

37 university satellites launched in 2003-2015

From CanSat to CubeSat, Nano-Satellite

From Educational purpose to Practical application

Launchers for 37 university satellites

- Foreign Rocket: 12
  - ROCKOT（Russia） 2 (2003)
  - COSMOS（Russia） 1 (2005)
  - PSLV（India） 3 (2008, 2012)
  - DNEPR (Russia) 6 (2014)
- Japanese Rocket: 25
  - M-V 2 （2006）
  - H-IIA 17 （2009～）
  - HTV⇒ISS deploy 6 （2012）

JAXA has been helping us for our activities!!

RAIKO, FITSAT-1 first deployment from ISS (2012.10)

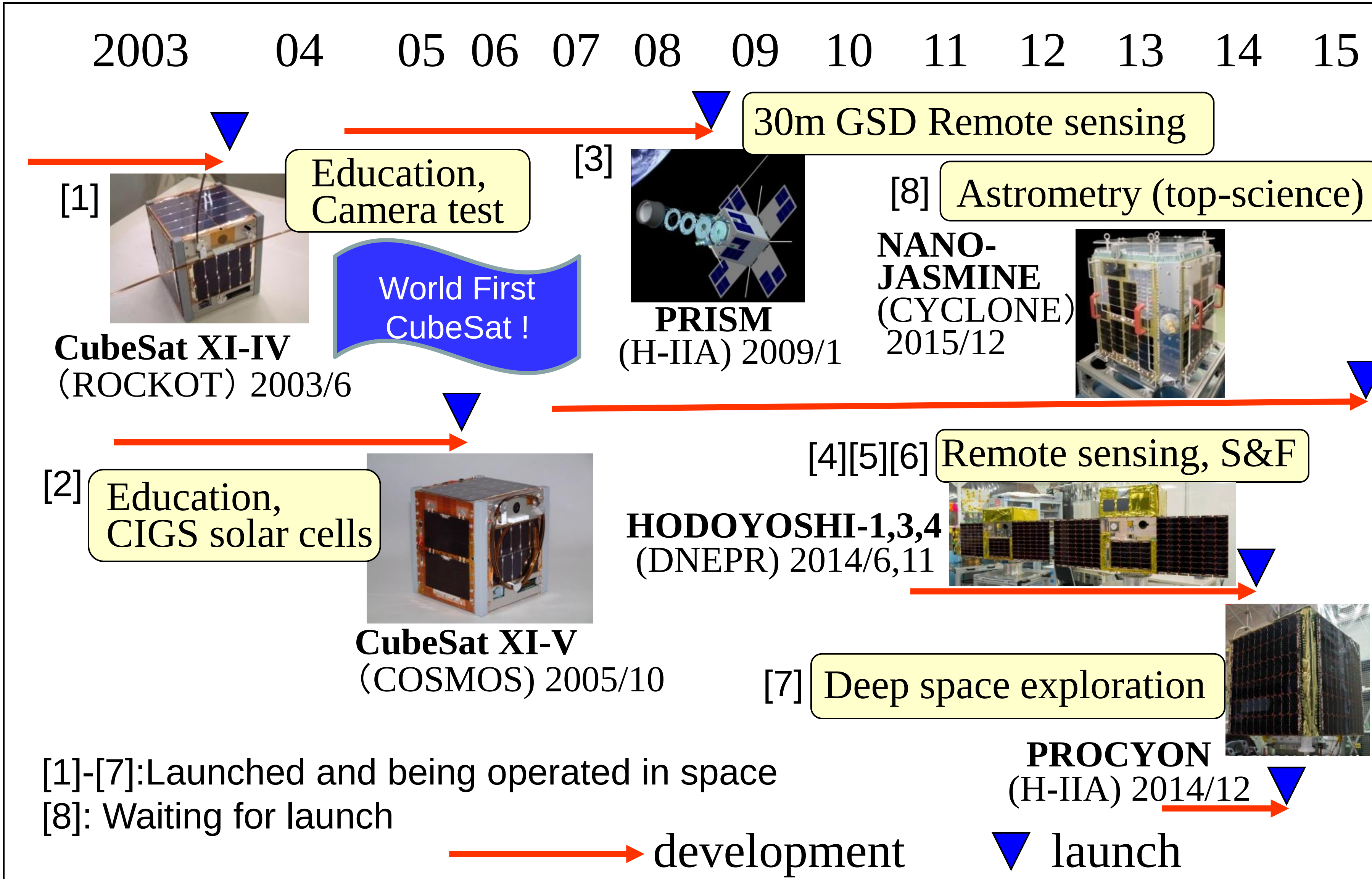
What is the special features about space systems?

- A satellite cannot be contacted until the end of its mission once it is loaded on a rocket and launched
  - "Non-maintainable system"
- Sometimes it should survive in space for more than 5 years without any human interactions, so

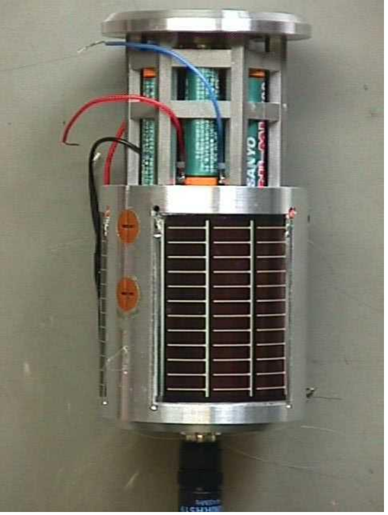
Carefully consider how to survive in space !!

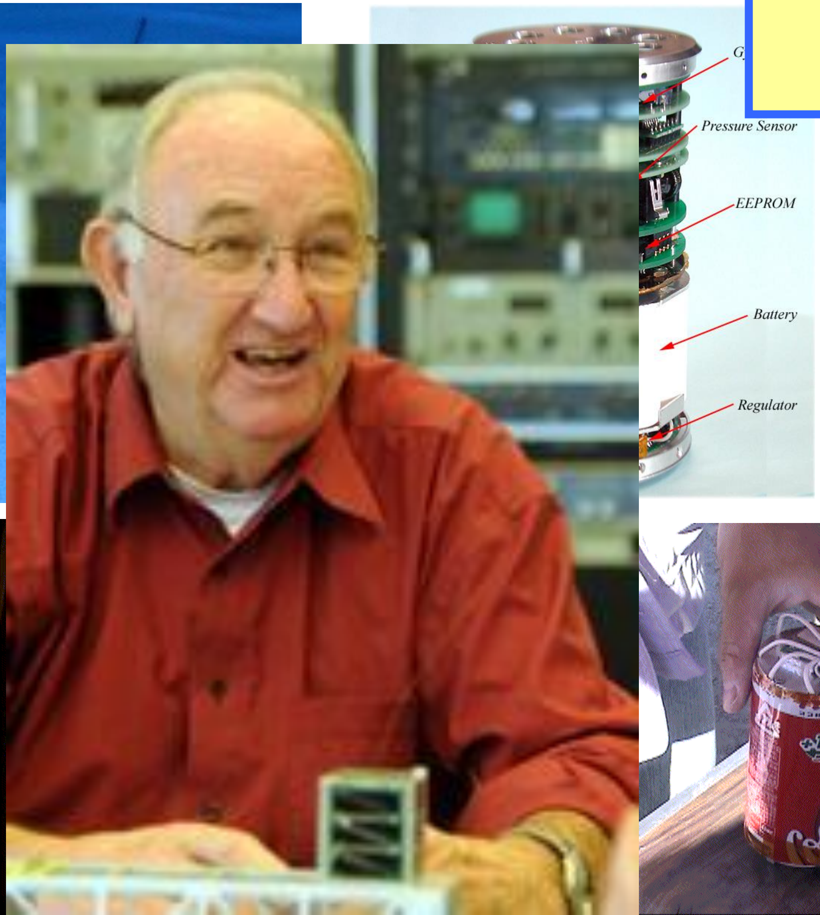
- Imagine all possible events and anomalies which may happen on satellites and prepare countermeasures for them as many as possible
- Focus on power system and communication system: to make it survive in any circumstances
- Don't skip required ground tests

University of Tokyo's History
8 satellites developed (7 launched)



Training step: CanSat 1999-now

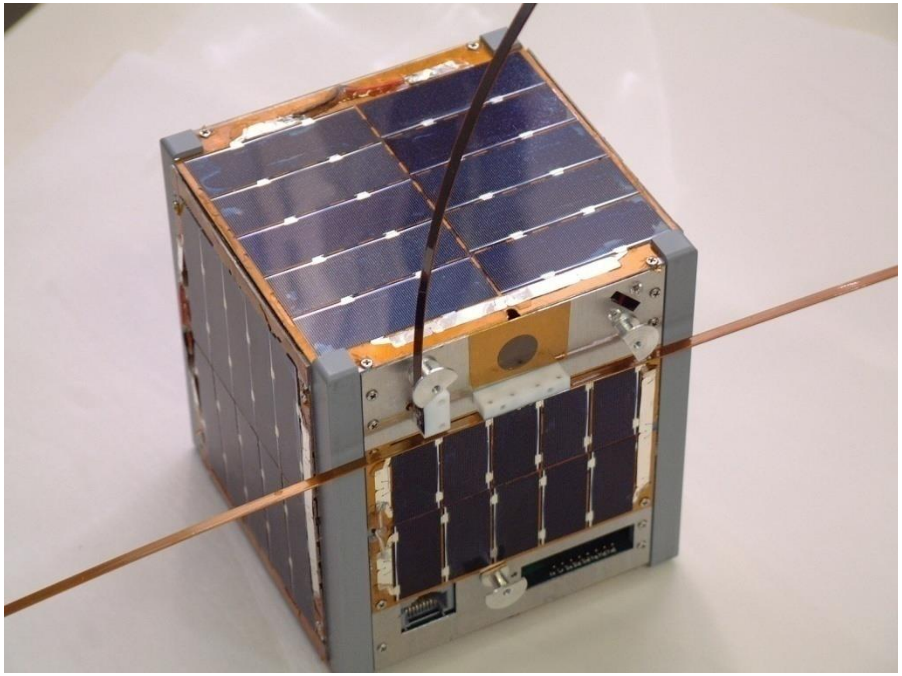




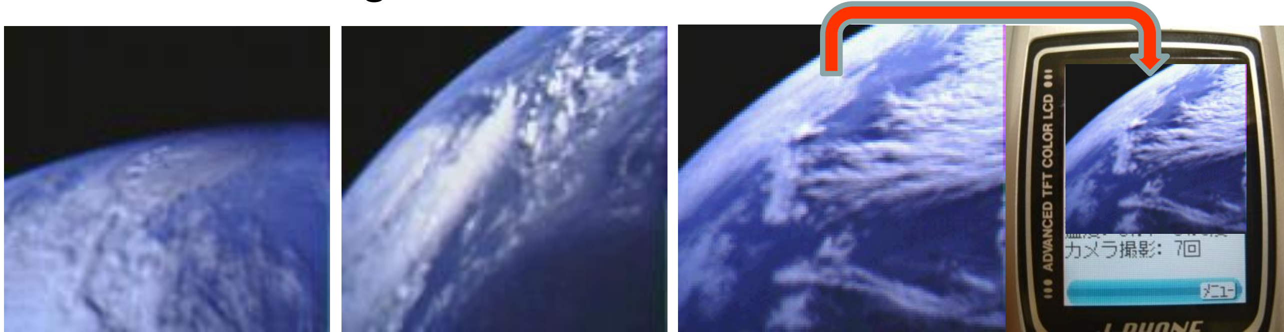
CubeSat “XI-IV (Sai Four)”

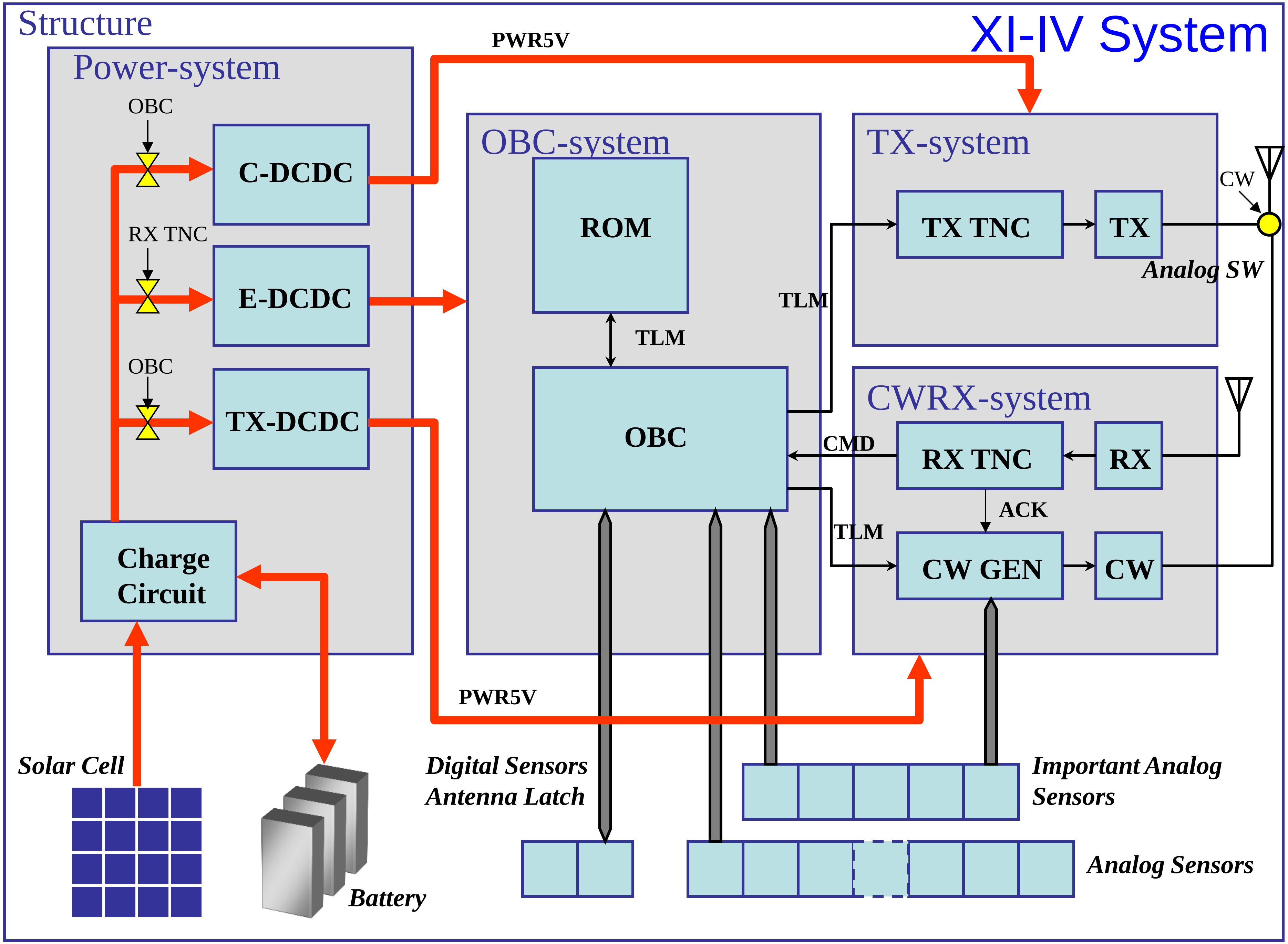
<u>Mission</u>: Pico-bus technology demonstration in space, Camera experiment
<u>Developer</u>: University of Tokyo
<u>Launch</u>: ROCKOT (June 30, 2003) in Multiple Payload Piggyback Launch

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
Expected life time	??



Captured Earth Images are Distribution to Mobile Phones



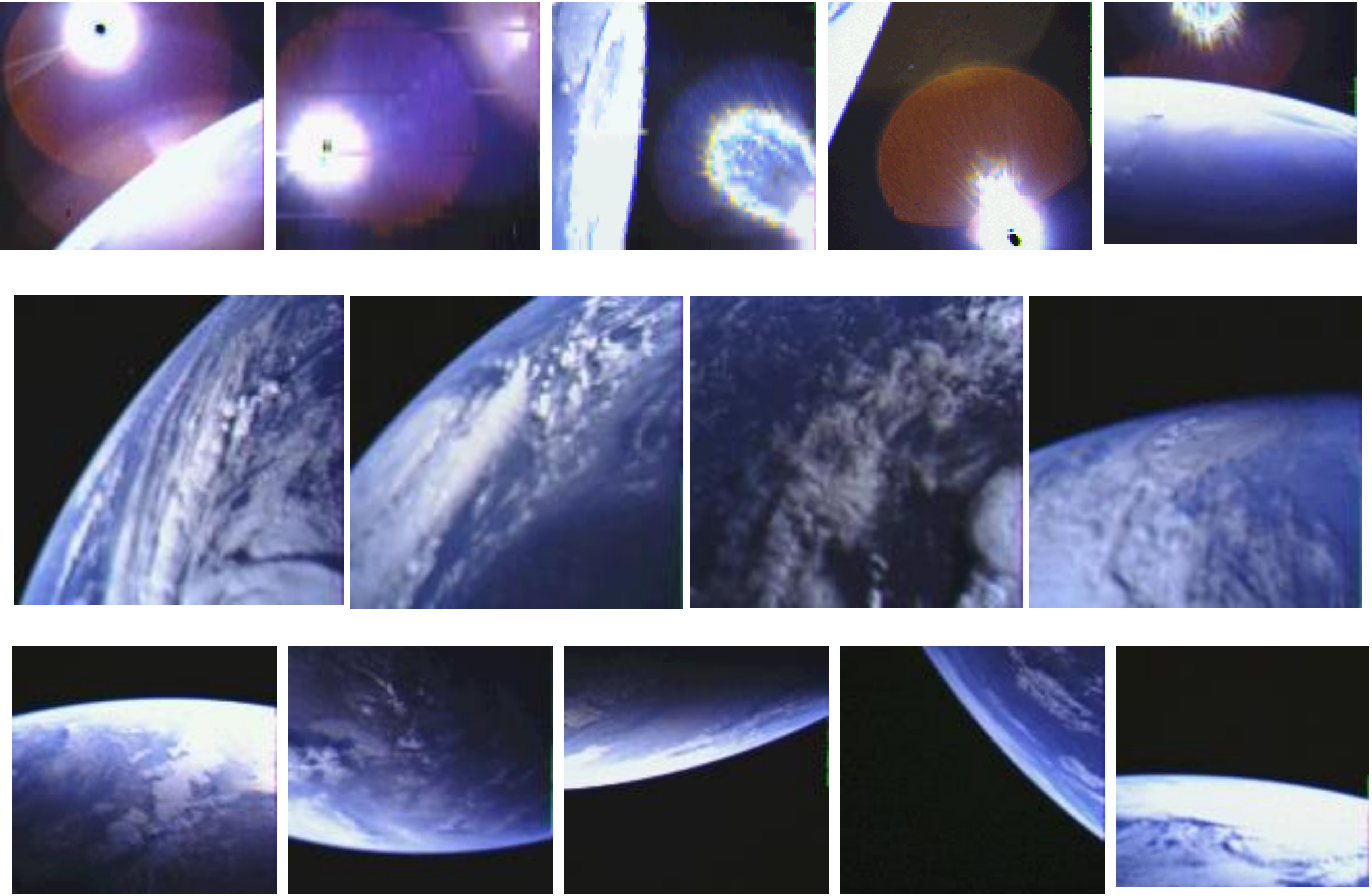

Structure
XI-IV System
Power-system
PWR5V
OBC
C-DCDC
RX TNC
E-DCDC
OBC
TX-DCDC
Charge Circuit
OBC-system
ROM
TLM
OBC
TX-system
TX TNC
TX
CW
Analog SW
TLM
CWRX-system
RX TNC
RX
CMD
ACK
TLM
CW GEN
CW
PWR5V
Solar Cell
Battery
Digital Sensors
Antenna Latch
Important Analog Sensors
Analog Sensors

Launch of the World First CubeSat (XI-IV, Cute-1 and others) by "ROCKOT"

2003/06/30 18:15:26 (Russia, Plesetsk time)

Project Manager of Hayabusa-2

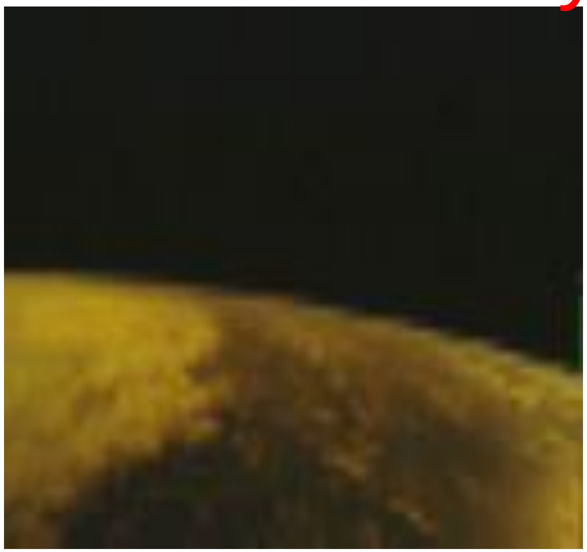
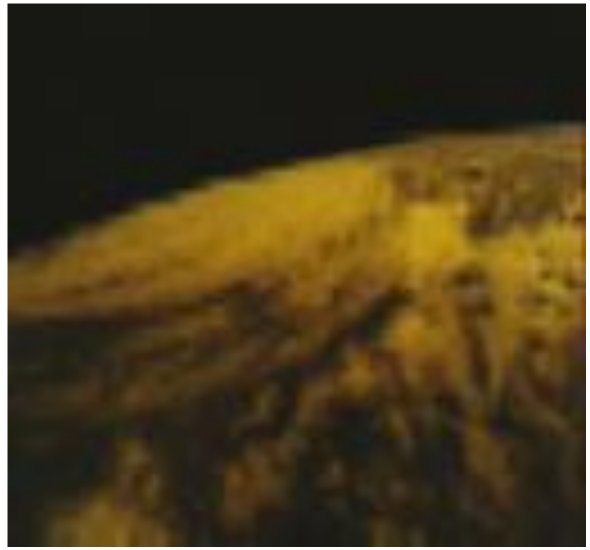
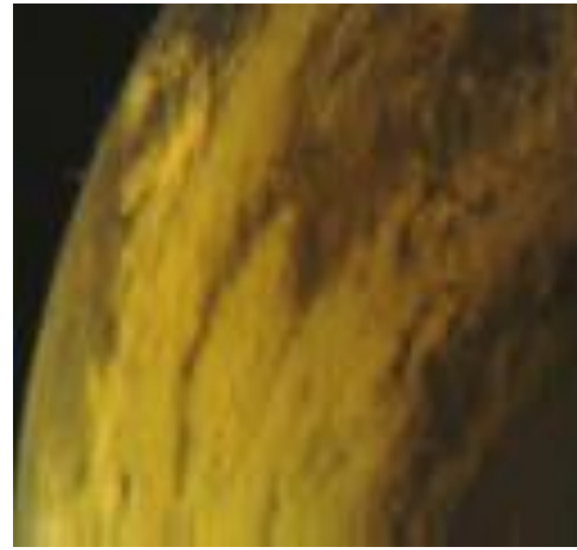
Surviving 13+ years with 500+ pictures downlinked

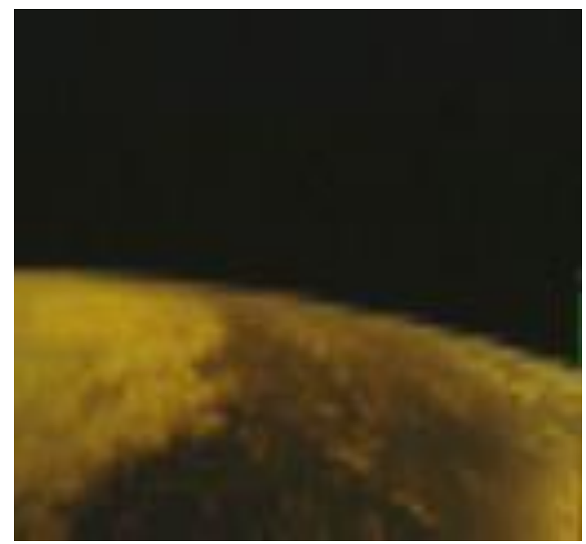


XI-IV is still perfectly working after 13 years in orbit

Recently Downlinked Photos

Sepia color !
Get older ?

2000 We started in situations that…

- No components on sales for CubeSat
  - – Everything should be “hand-made” by ourselves
- No ground test facility in our university

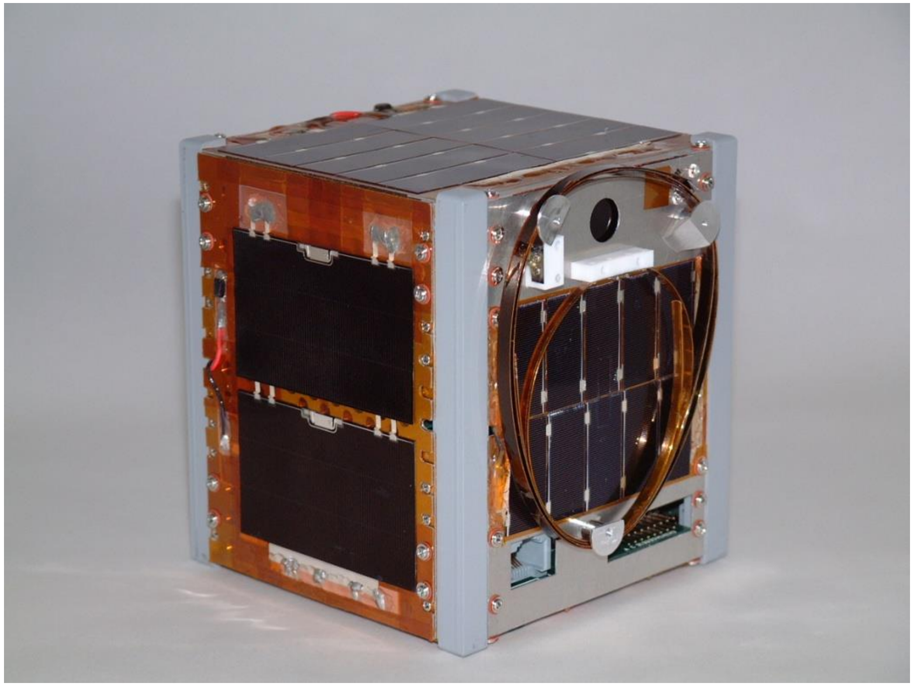
- Please find out what you can do with your small money or not-so-good facility
- Please find out the persons who know how to do and who are willing to support you

  - – We don’t know how to find launchers
  - – We don’t know how we can get frequency
  - – We don’t know how we can get export license
- But we could take much time to think & test

CubeSat “XI-V (Sai Five)”

<u>Mission</u>: CIGS solar cell demonstration, Advanced camera experiment
<u>Developer</u>: University of Tokyo
<u>Launch</u>: 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



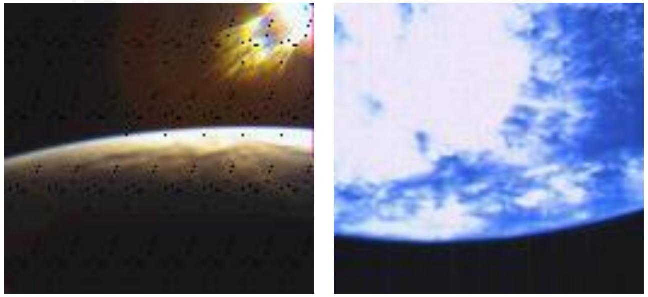
SSETI-EXPRESS

T-POD deployment System

Deployed from SSETI-EXPRESS in space

JAXA/NEDO CIGS Solar Cells

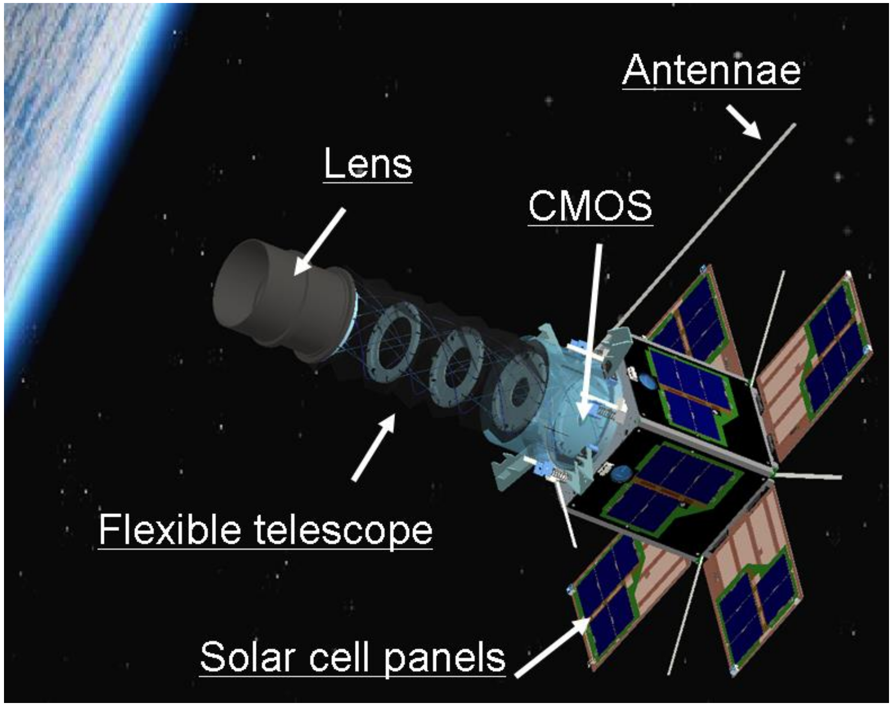
Captured Earth Images

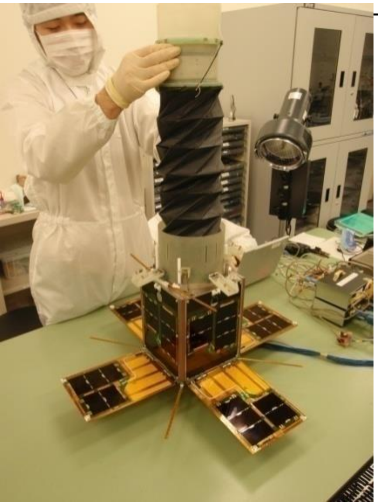


PRISM "Hitomi"

Mission: Earth Remote Sensing (20 m GSD, RGB) with Deployable Boom
Developer: University of Tokyo
Launch: H-IIA (Jan 23, 2009) Piggyback with GOSAT (CO_2 monitoring sat)

Size	20x20x40[cm] in rocket
	20x20x80[cm] in space
Weight	8.5 [kg]
Attitude control	3-axis stabilization with Sun, Magnet sensor, MEMS gyro magnetic torquers
OBC	SH2, H8 x 2, PIC x 2
Communication	VHF/UHF (max 9600bps)
Mission life	> 2.5 years





Captured images

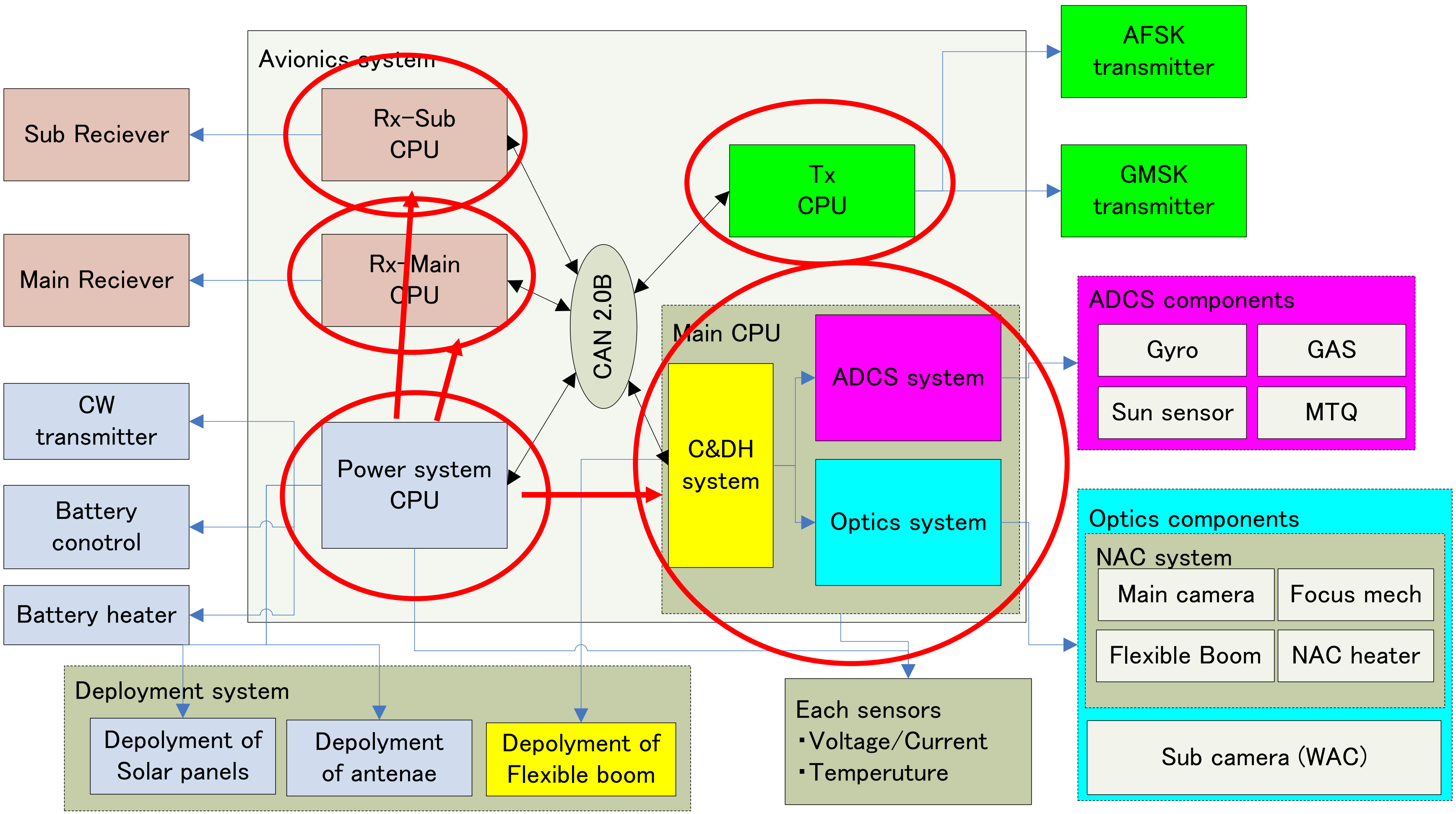
Mexico Seashore

US Desert

Kita-Kyushu (Japan)

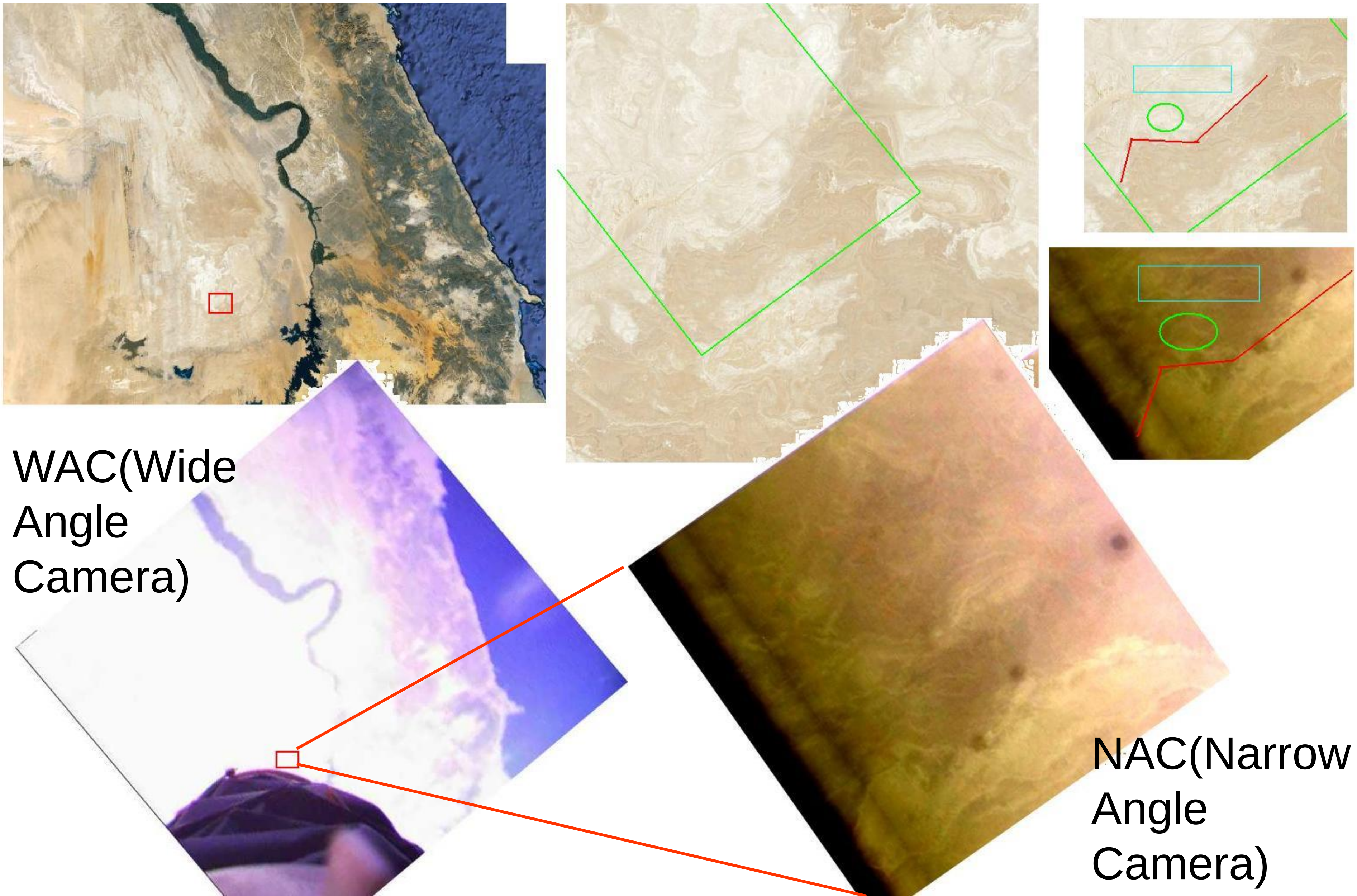
Wide Angle Camera

PRISMシステムブロックダイアグラム



Combination of "High performance but may-be-weak" processor and "Low performance but very robust and proven" processor

Photos of The Nile River



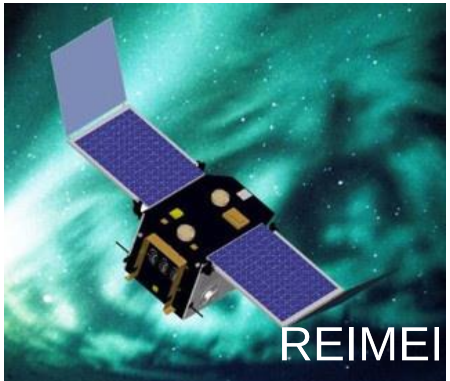
Important Tips for Development

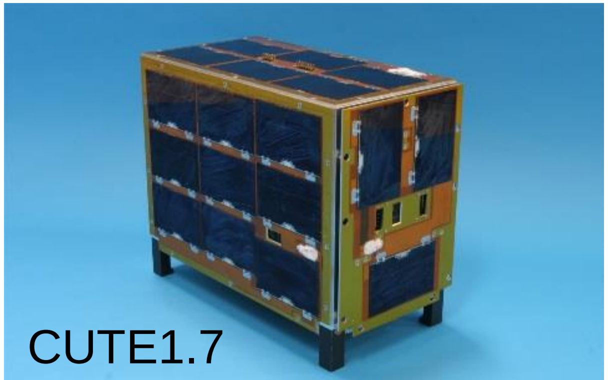
- Target level ("mission" or "bus" level)
  - Stepping up from Low/simple to High/complex
  - Transfer technology/experiences to next step
  - You can find highlight in even simple satellite
- "Kit" vs "Self-made"
  - Kit is very good to quickly get orbital results
    - But cannot understand the "inside of box"
  - "Self-made" will get deep understanding
  - Please find good combination of both strategy
- Don't think it an easy task
  - 100,000 man-hour were required for XI-IV

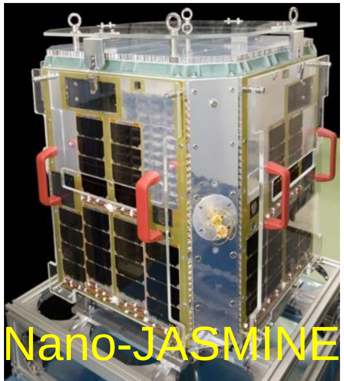
Vision on Applications to Space Science and Exploration

Space Science and Exploration
- Japanese Missions and Players -

Size(kg)	Cate gory	Players	Project Examples
>500	Mid-large	JAXA	Science: Ginga, Akari, Suzaku, Hitomi— Exploration: Hayabusa & 2, Kaguya, Akatsuki--
100-500	Small	JAXA	Science: Hisaki (2013), ERG (2016) ---- Engineering: Ikaros (2010)
20-100	Micro	JAXA University	Science: Reimei (Index, 72kg, 2005) Nano-JASMINE(38kg, 2017), RiseSat (2018) Exploration: PROCYON (58kg, 2014)
2-20	Nano	University	Science: CUTE-1.7+APD II (3kg 2008) Exploration: ECUULEUS (6U EM-1 2018)
<2	Pico		







UT's 4th Satellite:Nano-JASMINE

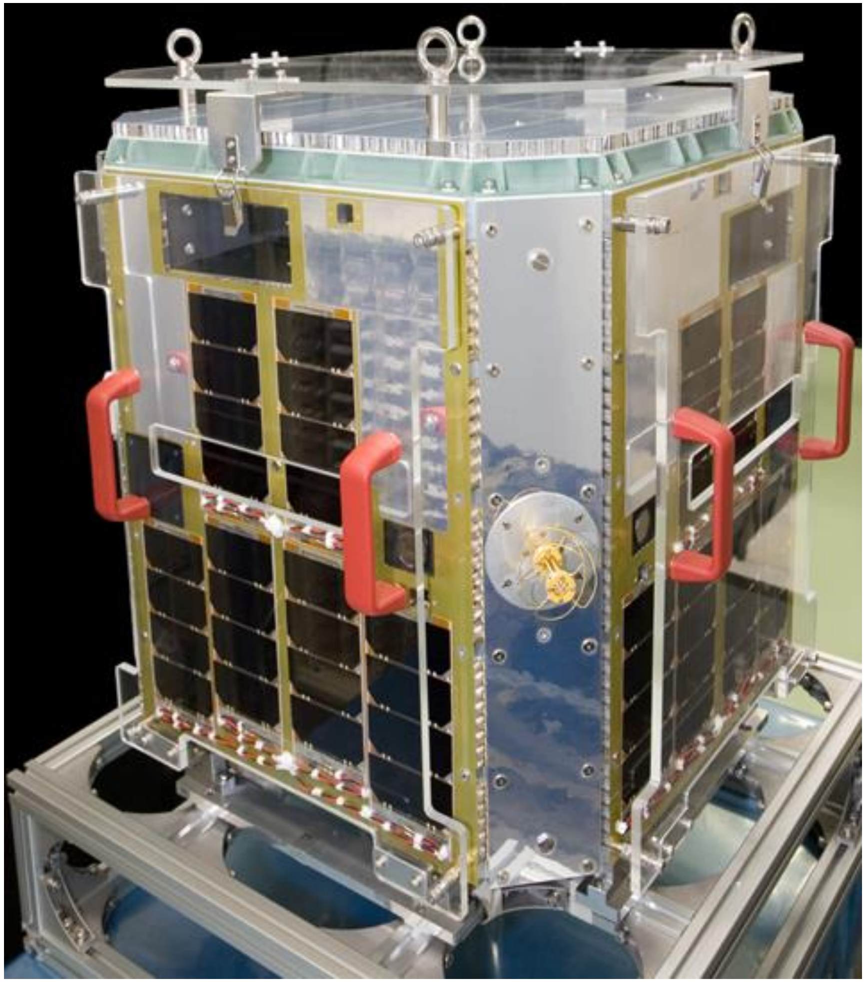
Intelligent Space Systems Laboratory
University of Tokyo
ISSL

Mission: Astrometry (Getting precise 3D map of stars and their movements)
Developer: University of Tokyo, National Astronomical Observatory of Japan, Shinshu University, Kyoto University
Launch: Initially CYCLONE-4 was planned but changed to another launcher

Size	50 [cm-cubic]
Weight	38 [kg]
Attitude control	3-axis stabilization with Star, Sun, Magnet sensor, FOG, RW, Magnetic torquers
OBC	FPGA
Communication	S-band 100 [kbps]
Mission life	2 [year]

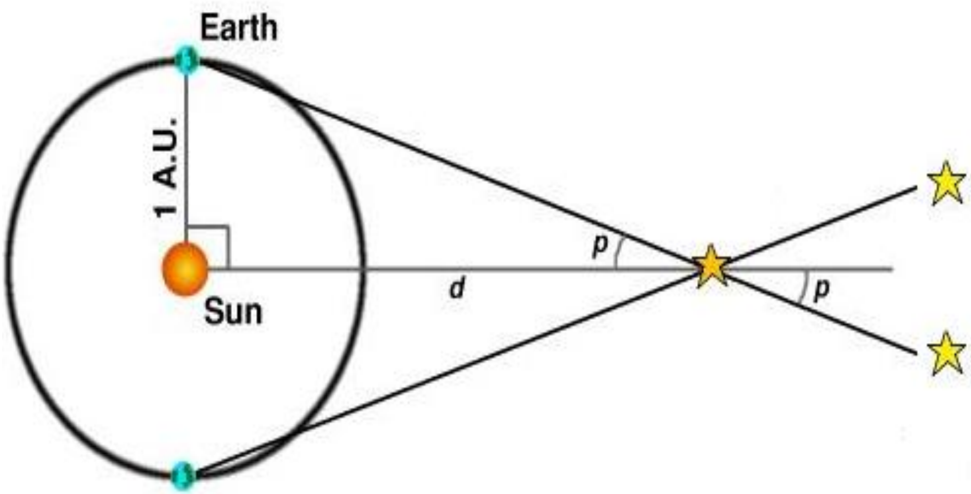
Special features:

-Attitude Stability	0.8 arcsec for 8.8 sec
-Thermal Stability	< 0.1K (at -50 degree)
-Map Accuracy	Compatible with "Hipparcos" Satellite ('89)
-Telescope	two CCDs with TDI



NJ’s “Astrometry” Mission

- **Mission**
  - **Estimate 3 Dimentional positions of stars and their movement**
  - **Demonstration for “JASMINE” mission**



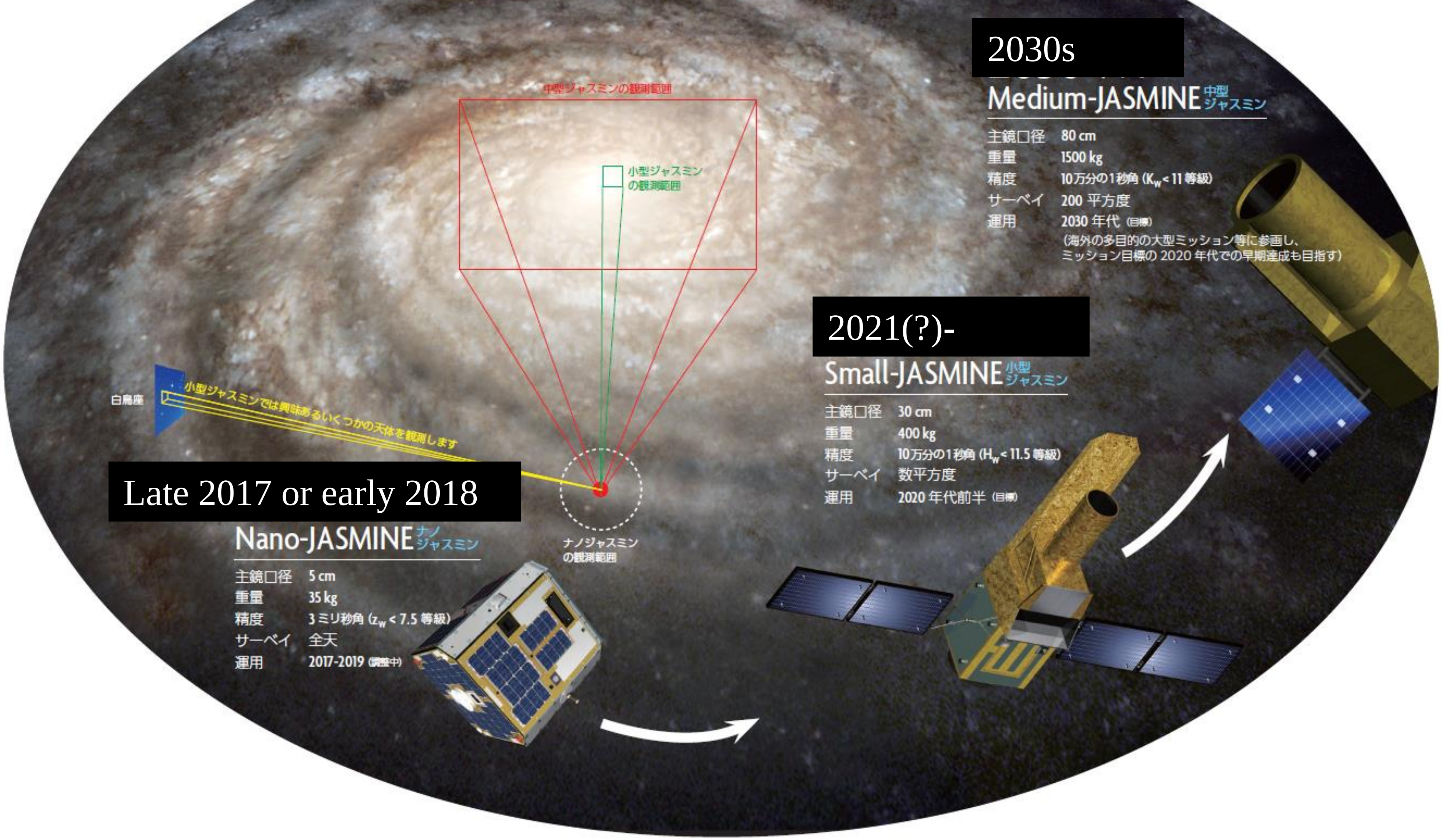
Star position determination by

Annual Parallax

- **Attitude stabilization**
  740 m-arcsec /8.8s
- **Temperature**
  - **50℃, ±0.1℃ stability**

- Long exposure time required.
- Two telescope angular separation should be kept constant.

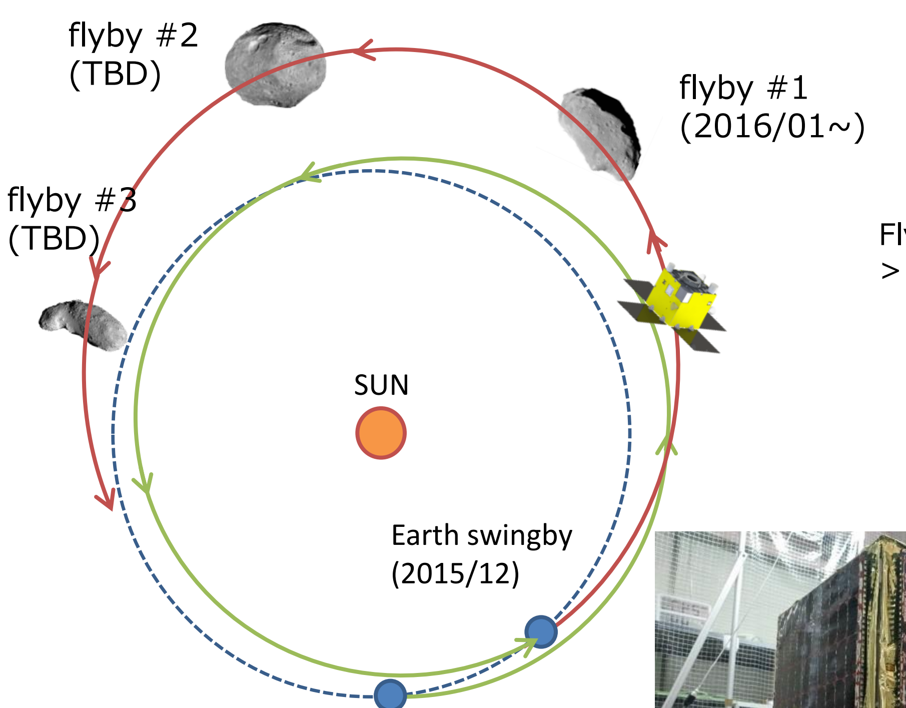
Japanese group is promoting series of space astrometry missions, “JASMINE program”, in international collaboration with Gaia DPAC team. JASMINE will play complementary roles of Gaia.



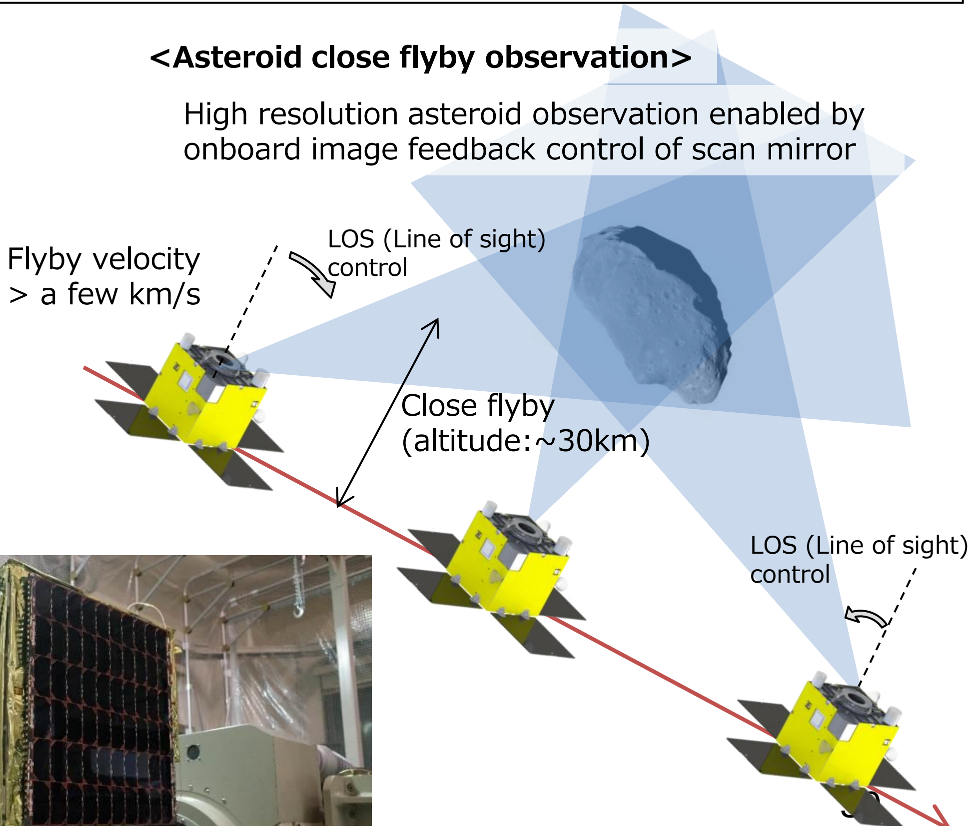
50kg-class deep space probe "PROCYON"

(PROCYON: PRoximate Object Close flYby with Optical Navigation)

Developer: **Univ. of Tokyo and JAXA** (Japan Aerospace Exploration Agency)
Launch: H2A rocket (together with Hayabusa-2 asteroid explorer, 2014 Dec.)
Mission: Demo. of 50kg deep space exploration bus system (nominal mission)
Asteroid flyby observation (advanced mission)



Launched (2014/12, together with Hayabusa-2 asteroid explorer)



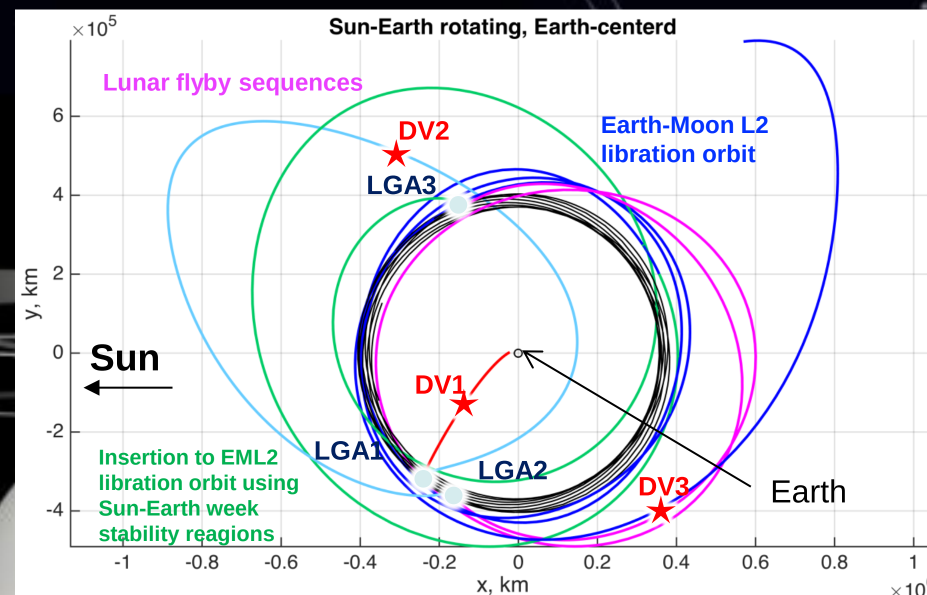
Used Hodoyoshi compo.
Developed within 1.2 years

Earth photos captured from deep space by PROCYON

Photos taken by PROCYON at close encounter of Earth in 2015/12 (one year after launch)

EQUULEUS One of 13 EM-1 CubeSats

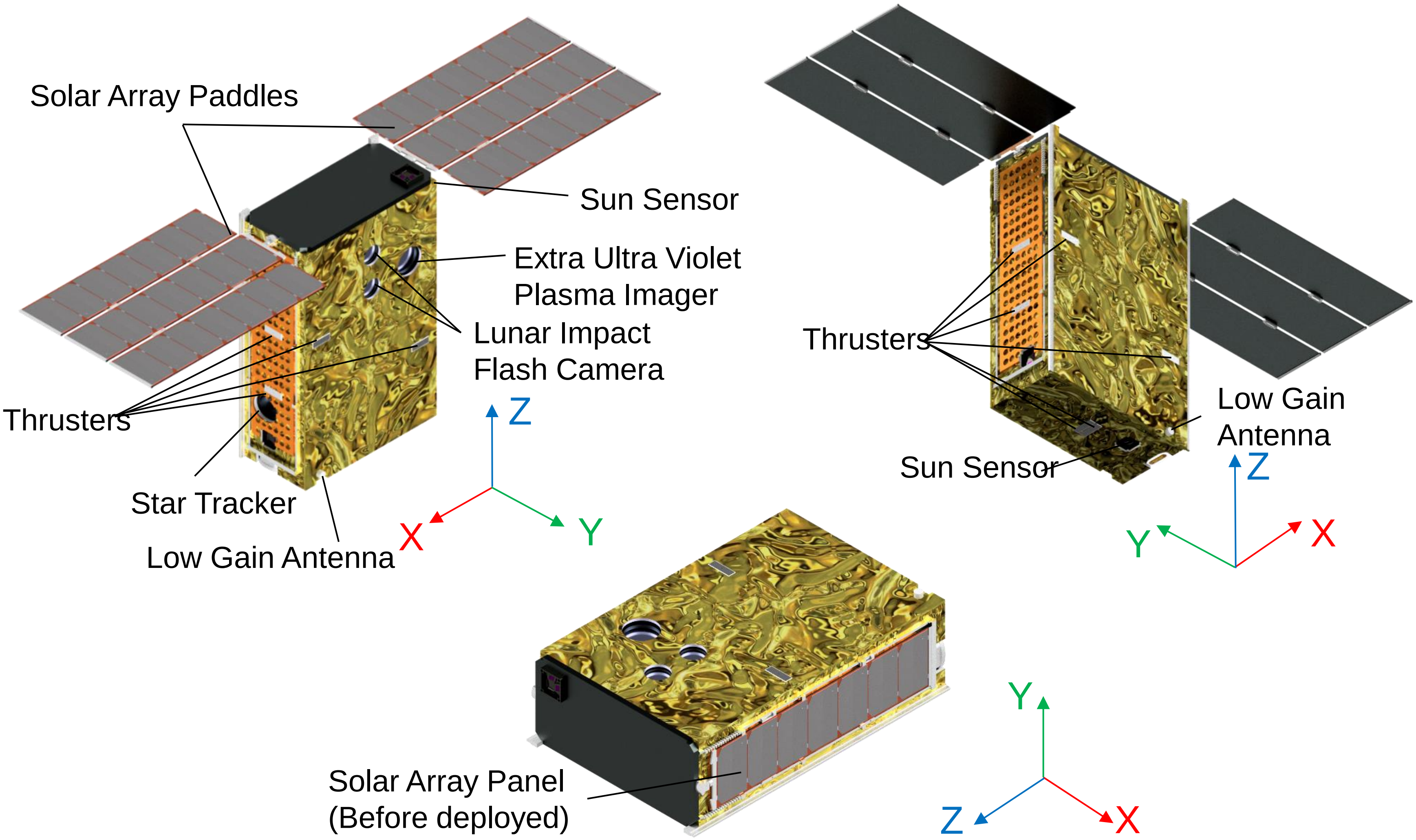
EQUilibriUm Lunar-Earth point 6U Spacecraft



Mission to Earth Moon Lagrange Point

Intelligent Space Systems Laboratory, 2016/08/01

Spacecraft Overview



EQUULEUS has fundamental bus systems for deep space missions within 6U CubeSat (deep space communication, power, thermal control, attitude control, propulsion).

Logic of "order"

Theoretical researchers require this but we relaxed…

10^{-13}

After severe discussions ….

10^{-7} → 10^{-9} ← 10^{-11}

Engineering prof.
"We can surely achieve this level."

"Let us compromise at this point !"

Science professors
"This is needed to aim at the top science"

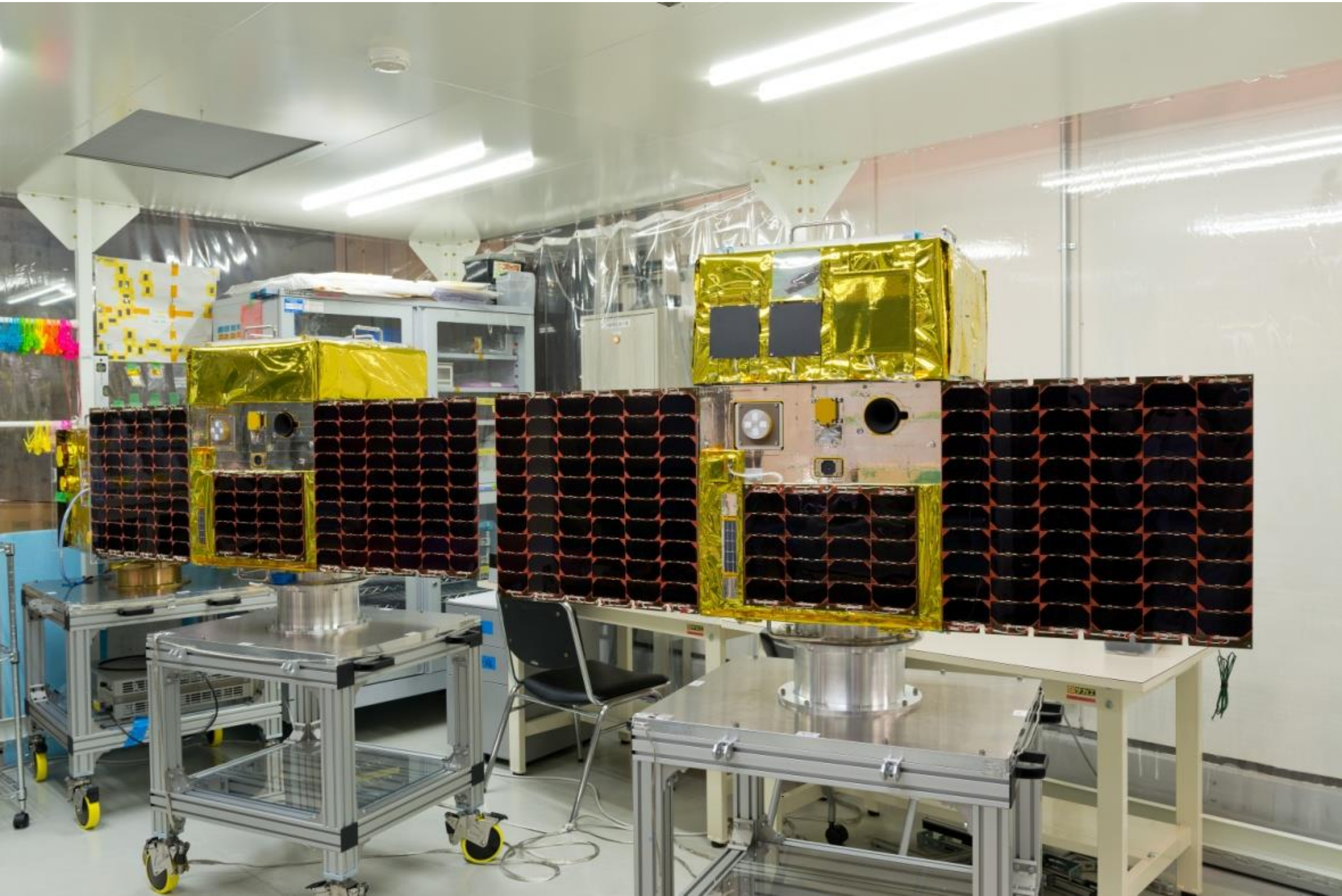
10^{-8} → 10^{-9} → 10^{-10}

Micro/nano-pathfinder	100-500kg-sat mission	Strategic class mission
< $ 10 M	< $ 100 M	< $ 300 M

If you pursue the "perfect" objective from initial, you cannot get money and you cannot realize as it is very difficult to get the public approval and funding. *Quickly start with "not perfect" but "good enough" science mission!*

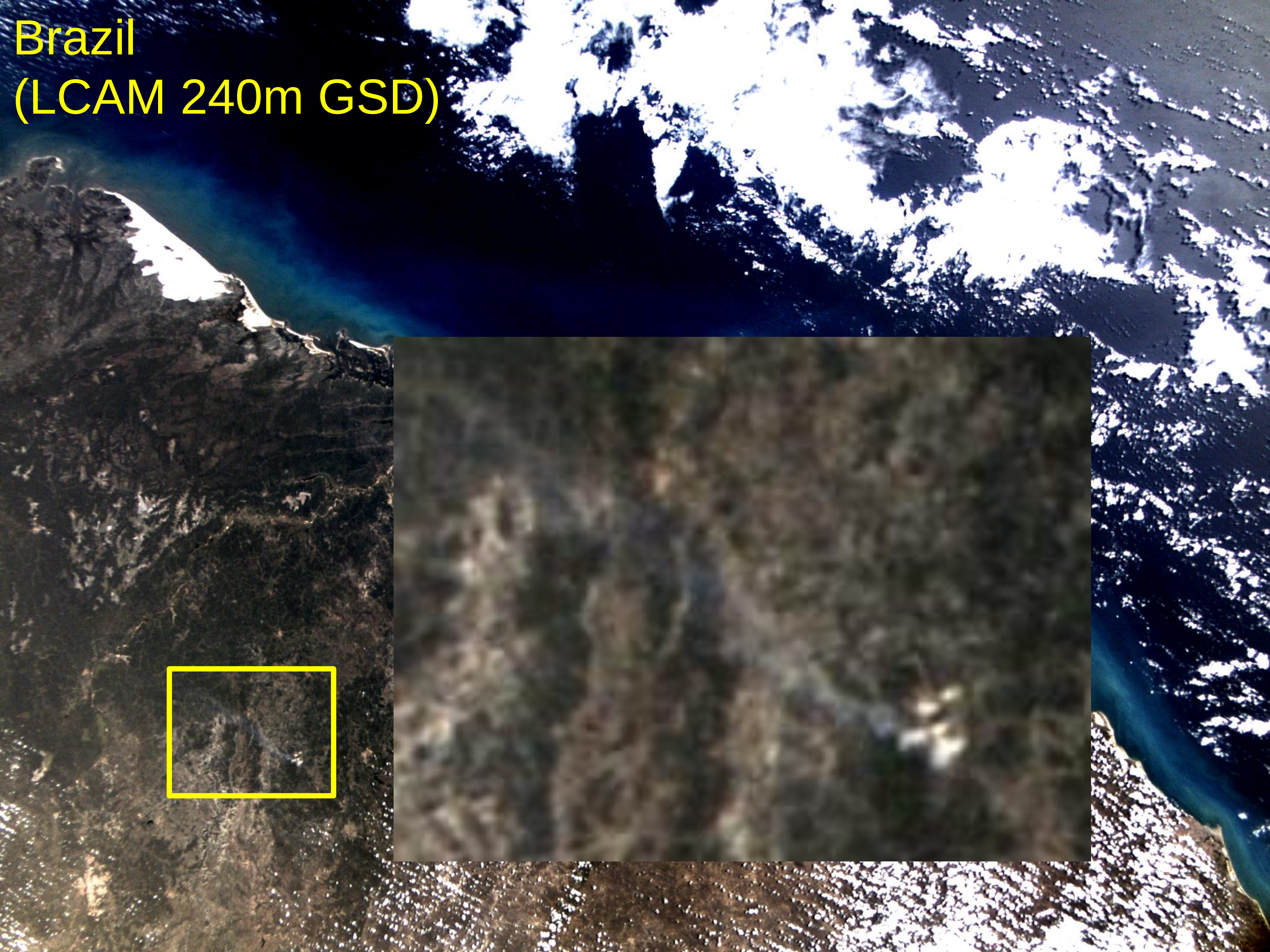
Vision on Applications to Earth Observation

Hodoyoshi-3 (left) and Hodoyoshi-4 before Shipment (April, 2014)



Implementation to Dnepr SHM 2014/6/10

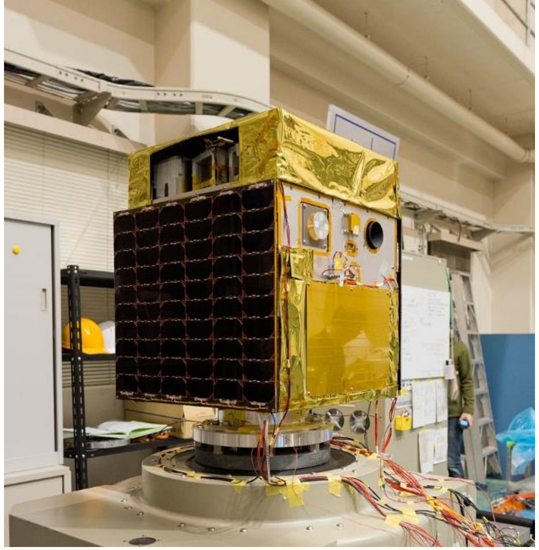

Sri Lanka
(LCAM 240m GSD)


Brazil
(LCAM 240m GSD)


Greek (false color)
(MCAM 40m GSD)


Chiba
(6m GSD)

MicroDragon Project
(50kg Earth Remote Sensing Satellite for Vietnam Engineers)



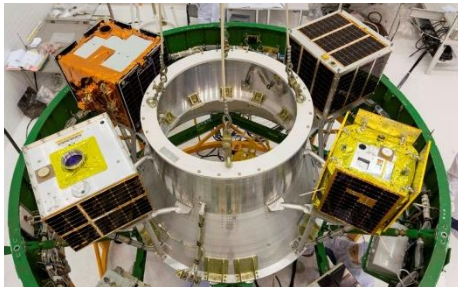
Total 36 engineers study and join the project in 5 Japanese universities. Launch by Epsilon rocket has been decided. (mid 2018).

The University of TOKYO		1st Academic Year 2013/10-2014/9	2nd Academic Year 2014/10-2015/9	3rd Academic Year 2015/10-2016/9	4th Academic Year 2016/10-2017/9
Project Schedule	Satellite System Rough Deign & CanSat Hand-on				
	Mission Definition Review		Oct		
	Satellite Preliminary Design/Engineering Model				
	Preliminary Design Review		May		
	Detail Design				
	Critical Design Review			Dec	
	Flight Model Manufacture				
	System Integration & Test				
	Launch Readiness Review				Jan 2017
	Ground Station Preparation & Practice				

HODOYOSHI-1

Mission: Earth Remote Sensing (6.7m GSD, 4 bands: RGB & NIR)
Developer: AXELSPACE, University of Tokyo, NESTRA
Launch: DNEPR launch on November 6, 2014

Size	about 50 [cm-cubic]
Weight	60 [kg]
OBC	FPGA
Communication	UHF, X (10-20 Mbps)
Average power	50 W
Attitude control	3-axis stabilization with STT, SAS, Magnetometer, Gyros, RW, Magnetic torquers
- stability	0.1 deg/sec
- pointing accuracy	5 arcmin
- determination	10 arcsec
Optical sensor:	15kg, 6.7m GSD (500km alt.)
- Focal length	740mm (F# 7)
- Swath	27.8 x max 179km (500km alt.)
- Bands(SNR)	B(57), G(74), R(80), NIR



Optical Camera (6.7m@500km)
developed by Genesia Corporation


New Zealand
©AXELSPACE


Dubai (6.7mGSD)
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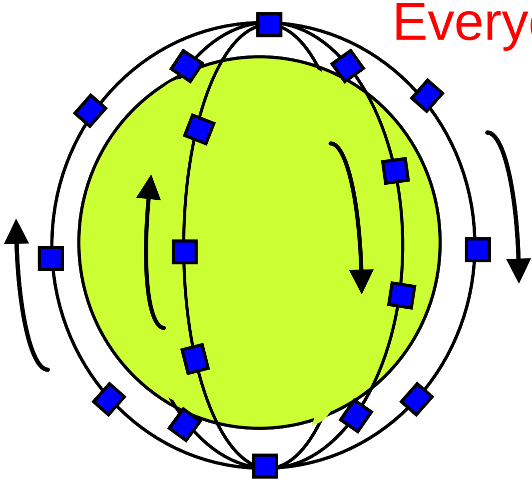
Future Plan of AXELSPACE

- GRUS（3 sattellites in 2017, 50 sats in 2022)

Everyday coverage of the whole globe



2.5m resolution images

- WNISAT-1R (to be launched in 2016 spring)

- Glacier Observation of arctic ocean
- GNSS-R reflection experiment
- Laser communication experiment

Vision on Applications to Novel Type of Missions

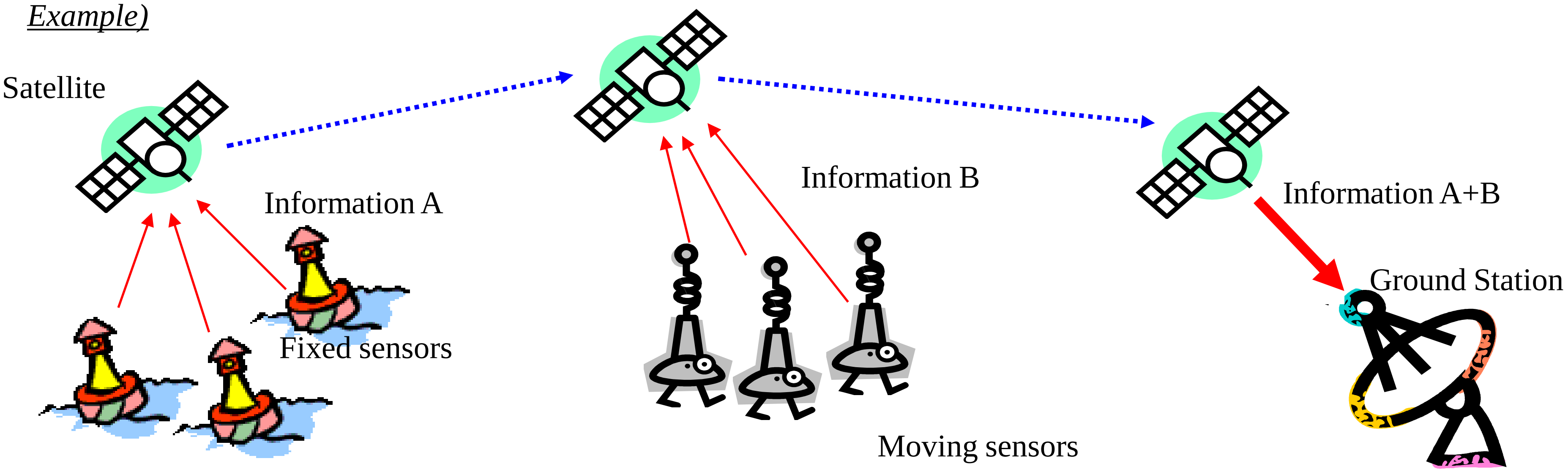
"Store & Forward" gets ground information

- UHF receiver onboard Hodoyohi-3 & 4 can collect data from ground Sensor Network (fixed points or mobile)

<u>S&F mission outline</u>

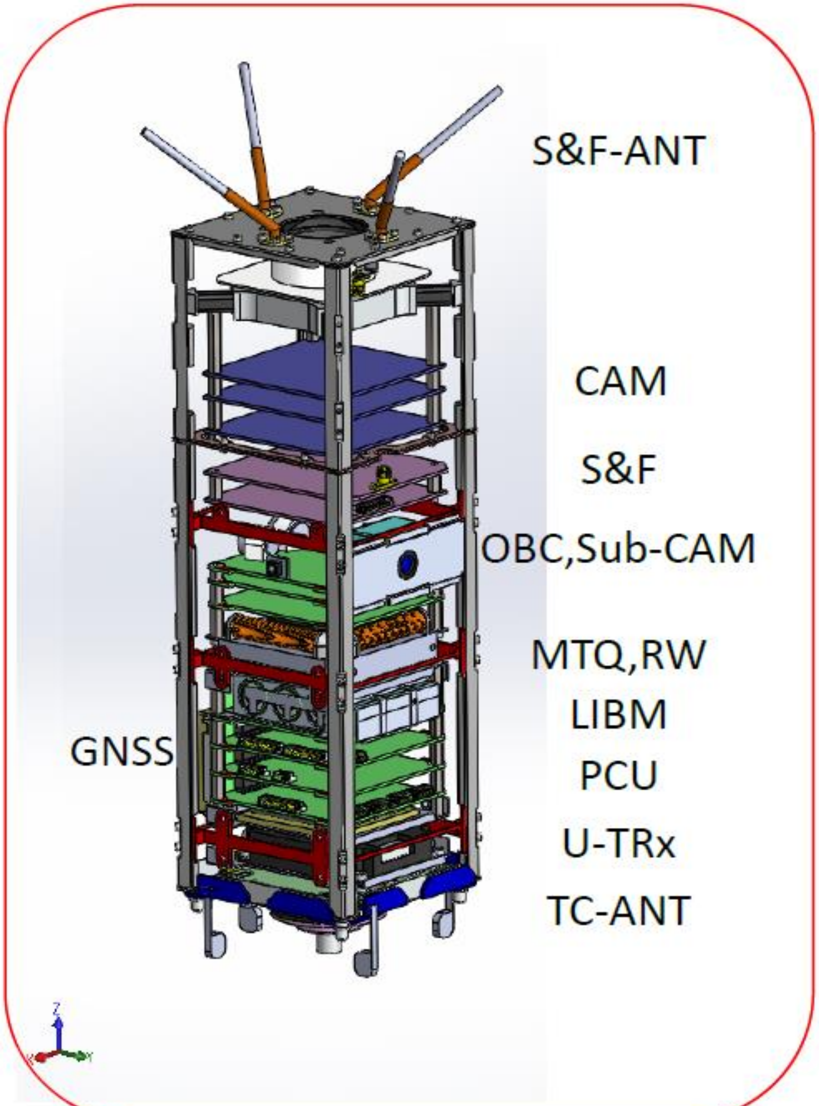
1. Fixed or mobile sensors on the earth get ground information and transmit them to Hodoyoshi-3&4 when they fly over the area
2. Hodoyoshi 3&4 receive and store the information, and forward (transmit) it to Ground Stations when it flies over them

<u>Example)</u>



Application areas: disaster prediction, water level monitoring, forest data acquisition…..

3U CubeSat “TriCom-1”
- Store & Forward Test Satellite -

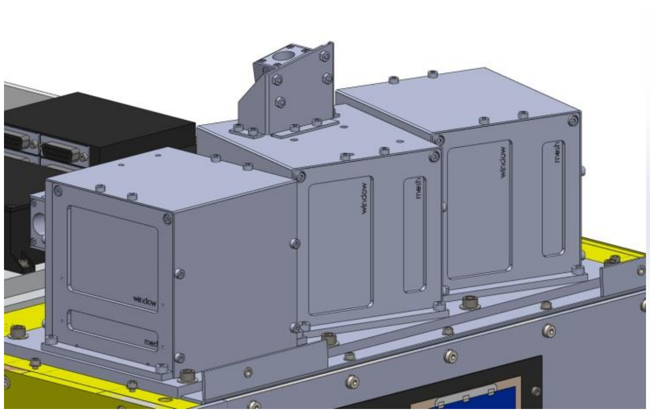


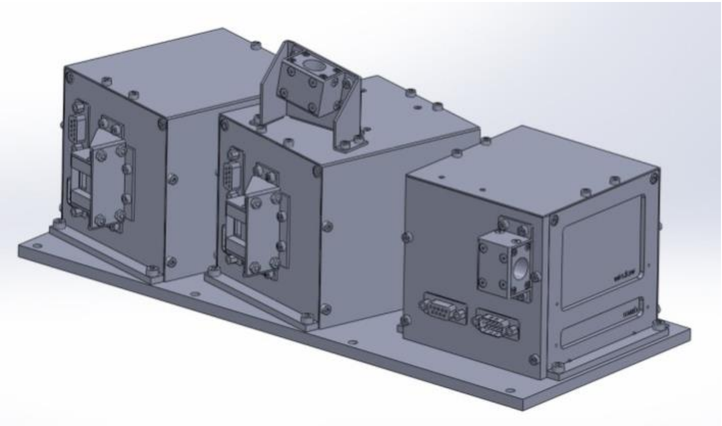
Items	Values	Miscellaneous
Size	10x10x30cm	3U size
Weight	< 3kg	
OBC	"Bocchan"board	Internal made
Power (average)	4W	AZUR GaAs cell
Battery	Li-Ion 41 wh	LIBM
Downlink (H/K&data)	W 1.2kbps	460MHz AFSK "U-TRx"
Uplink(H/K)	50W 9600bps	401MHz
Attitude	Simple 3 axis	B-dot law only
Sensor	magnetic sensor, gyro GPS receiver	"GNSS"
Actuators	magnet torquer despun wheel	"MTQ" "RW"
Camera	GSD 314 m VGA @180km	"CAM"
Sub-Camera	GSD 67 m @600km	"Sub-CAM"

Weak Signal Receiver for Data Collection Capability

Item	Specification
bit rate	100 bps, maximum 8 channels in parallel
Transmission duration	< 300 sec
Transmission power from ground	20 mW
Frequency band	920 MHz (no license of usage is required if using 20mW power)

“Rental Space” in Hodoyoshi 3 & 4





Provided Services:
-Electric power
-Information line
-Camera
-Windows

- Vacant spaces of 10cm cubic size, which are sold to customers
- To provide the “orbiting laboratory” or “advertisement room” opportunity for companies, researcher, public
    - Space demonstration of new products
    - Space environment utilization (micro-gravity)
    - Space science, etc.


Inside of 10cm Cubic Space
HELLO KITTY
40TH
ANNIVERSARY
This message can be uplinked
"Moving Earth" as seen through the window
20 second video clip is downlinked and sent to Sanrio
©1976, 2014 SANRIO CO.,LTD.

UNISEC and International Collaborations

University Educational Community **UNISEC**
(UNIversity Space Engineering Consortium)

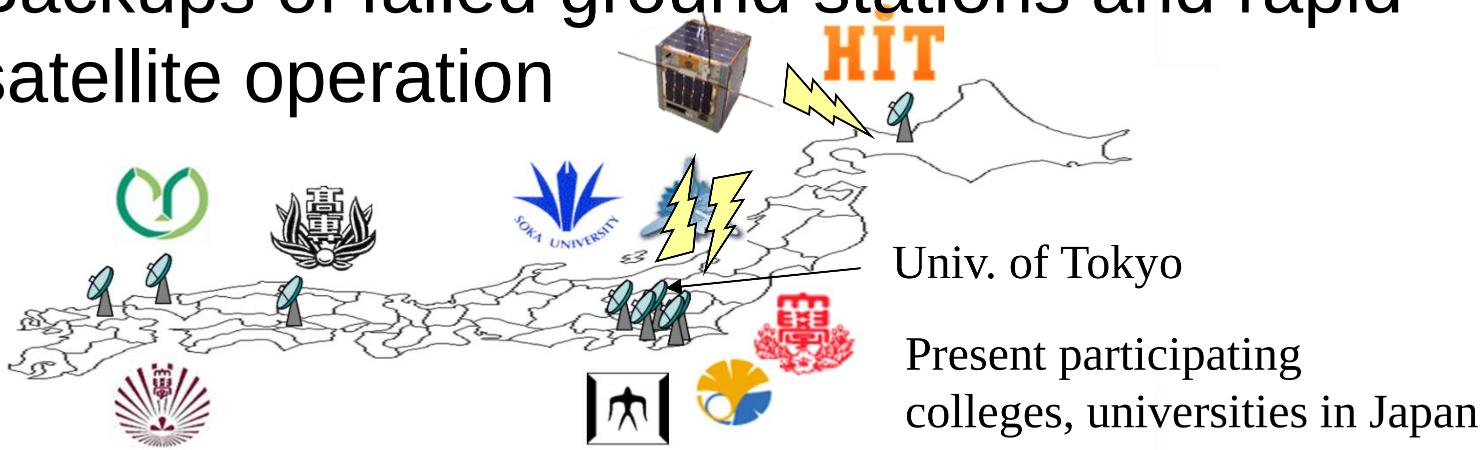
- Founded in 2002, became NPO in 2003
- 70 laboratories from 50 universities (2015)
- 811 students, 267 individual/company members
- UNISEC Missions:
  - Education and human resource training for space development/utilization
  - Innovative space technology “seeds” development
- Activities to be Supported:
  - Joint experiment, joint development, joint education, etc.
  - Workshop, symposium, technology exchange, etc.
  - Consultation on legal matters (frequency, export law, etc.)
  - Finding “rivals” within the community !
  - “UNISEC Lecture Series”

UNISEC
University Space Engineering Consortium

http://www.unisec.jp

Ground Station Network (GSN)

- If many universities' ground stations are connected by internet, then it provides
  - Extended operation windows of their own satellite.
  - Backups of failed ground stations and rapid satellite operation



- Worldwide network is under construction
  - Germany (Wurzburg), Sweden (Lurea Univ. in Kiruna),
  - USA (Calpoly, Hawaii, Stanford, Santa Clara, etc)

CLTP History & Participants

48 participants from 25 countries

CLTP1 (Wakayama Univ. in Feb-March, 2011)

12 participants from 10 countries, namely Algeria, Australia, Egypt, Guatemala, Mexico, Nigeria, Peru, Sri Lanka, Turkey (3), Vietnam.

CLTP2 (Nihon Univ. in Nov-Dec, 2011)

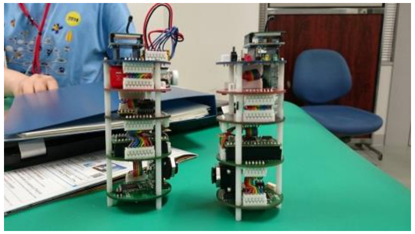
10 participants from 10 countries, namely Indonesia, Malaysia, Nigeria, Vietnam, Ghana, Peru, Singapore, Mongolia, Thailand, Turkey.

CLTP3 (Tokyo Metropolitan Univ. in July-August, 2012)

10 participants from 9 countries, namely Egypt (2), Nigeria, Namibia, Turkey, Lithuania, Mongolia, Israel, Philippines, Brazil.

CLTP4 (Keio Univ. in July-August, 2013)

9 participants from 6 countries, namely Mexico(4), Angola, Mongolia, Philippines, Bangladesh, Japan.



CLTP5 (Hokkaido Univ. in Sept 8-19, 2014)

7 participants from 5 countries, namely Korea (2), Peru, Mongolia, Mexico (2), Egypt.

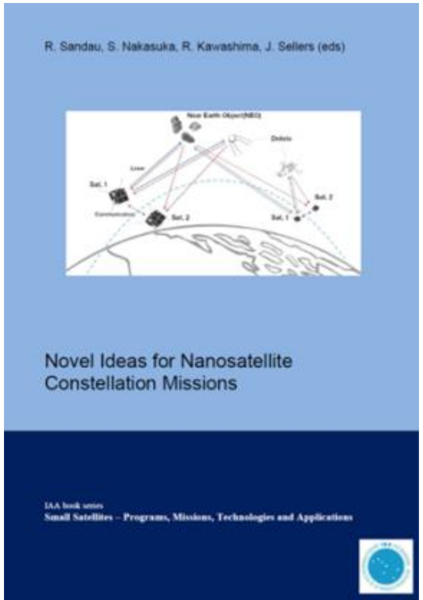
CLTP6 (Hokkaido Univ. in Aug, 2015)

Mission Idea Contest (MIC) for Micro/nano satellite utilization

The 3rd **Mission Idea Contest** for Micro/Nano-satellite Utilization

Pre-4th Mission Idea Contest Workshop

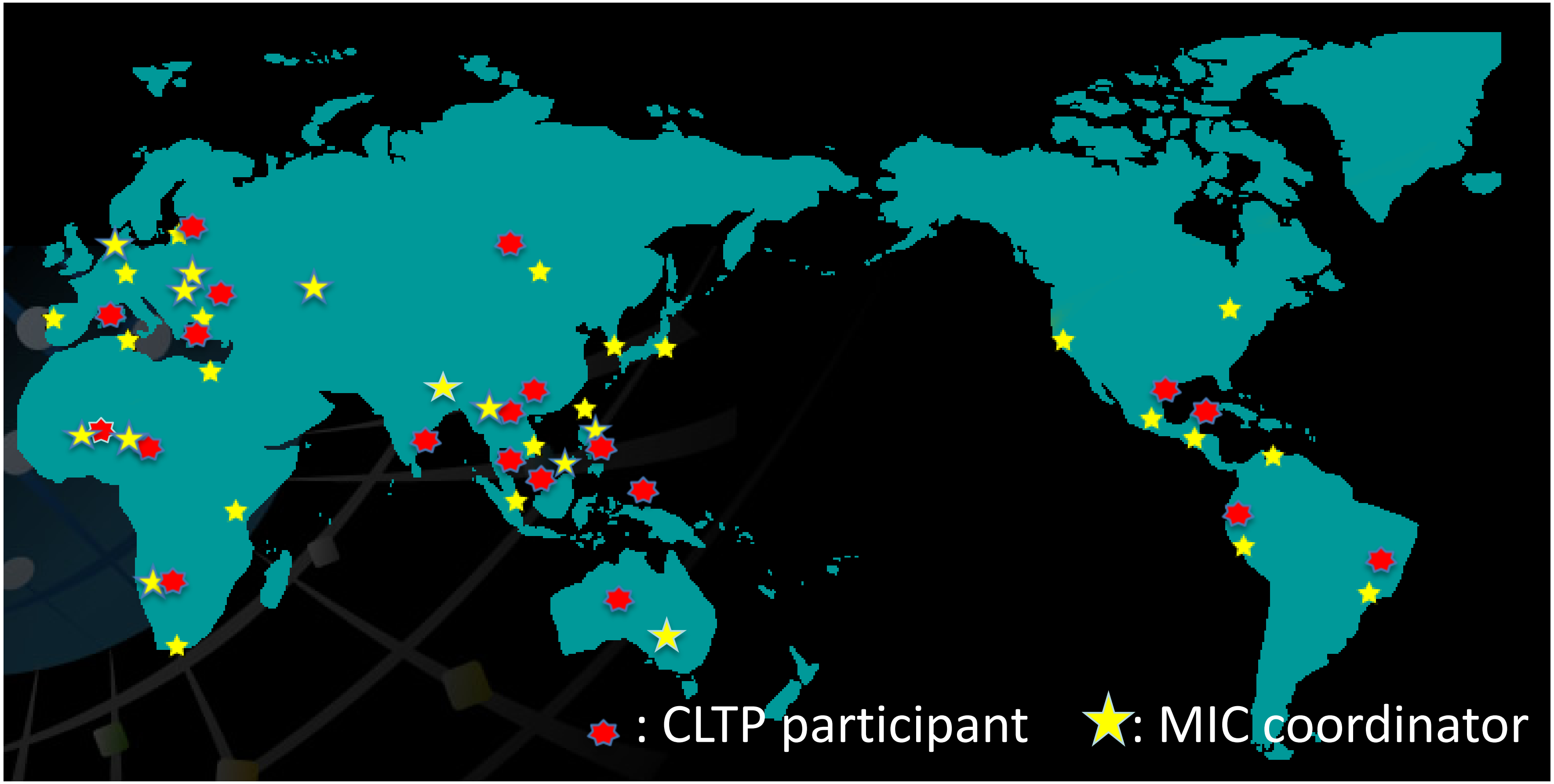
- Mission and satellite design idea for less than 50kg micro/nano/pico-satellites
- Regional coordinators: 33
- History
  - MIC1 in Tokyo, March 14, 2011
  - MIC2 in Nagoya, Oct. 10, 2012
  - PreMIC3 in Tokyo, Nov. 23, 2013
  - MIC3 in Kitakyushu, Nov 19, 2014
  - PreMIC4 in Tokyo, July 3, 2015
  - **MIC4 to be held in Varna, Oct, 2016**



Global network through MIC and CLTP (MIC:33, CLTP: 21 nations) 38 countries in total

260 attendants from 47 nations in 5th Nano-sat Sympo 2013.

<u>7th Nano-sat Sympo will be held in October 2016 in Varna.</u>



- MicroDragon is developed with 36 Vietnam young engineers in four years
- Collaboration with Kazakfstan, Brazil, Ukraine, etc. is under discussion

“UNISEC-Global” activities

33 regions/countries are interested to start UNISEC in their countries: South Africa, Angola, Namibia, Egypt, Ghana, Kenya, Nigeria, Tunisia, Bangladesh, Korea, Mongolia, the Philippines, Singapore, Taiwan, Thailand, Turkey, Australia, Indonesia, Saudi Arabia, Canada, USA, Guatemala, Mexico, Peru, Brazil, Bulgaria, Italy, Samara (Russia), Switzerland, Germany, Slovenia, Lithuania and Japan.

12 Local Chapters and 1 Association of Local Chapters have been acknowledged. (red part)

UNISEC-GLOBAL meeting will be held in Varna in October 2016

Summary

- The era of micro/nano/pico-satellites has come !!
- Not only “launch”, but also make it really work and perform missions in space !!
  - To make it survive in space !
- Stepping up from simple to sophisticated satellites would be a good strategy !!
- Enjoy this one week joint event and find new friends and collaborators !!