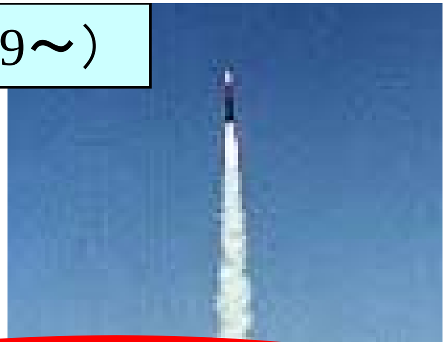
CanSat & Rocket Experiment('99～)



Hodoyoshi-1 '14

Current Status and Future Vision of Hodoyoshi Microsatellites – Systems for Quick and Affordable Space Utilizations

Shinichi Nakasuka
University of Tokyo

CubeSat 03,05

PRISM '09

Nano-JASMINE '13

Pre-”Hodoyoshi”

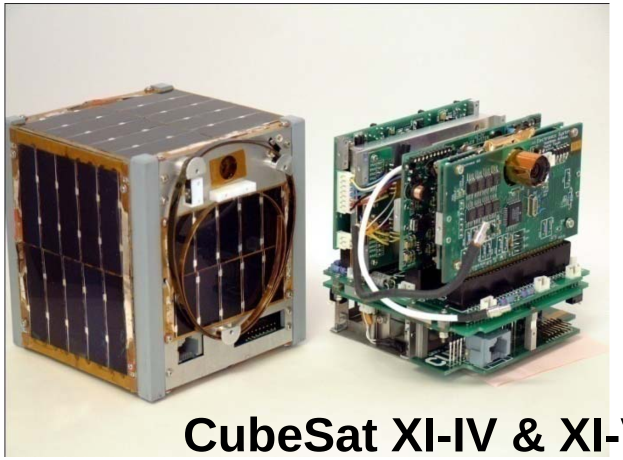
“University Satellites” Activities
in Japan

Emerge of Nano/pico-Satellites in Japan

Success of CubeSat(1kg) by Univ. Tokyo and Titech (2003.6.30)

- University level budget (30K$)
- Development within 2 years
- Surviving in space for >10 years
- Ground operations, frequency acquisitions, launch opportunity search processed by ourselves

1～50kg (Micro/Nano-sat):
Starting from education but higher level satellites appears


CubeSat XI-IV & XI-V

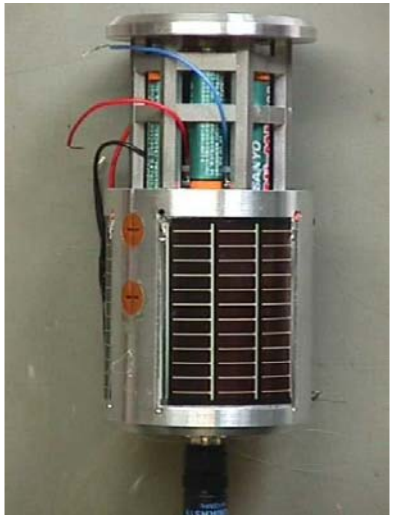

Russian Launch

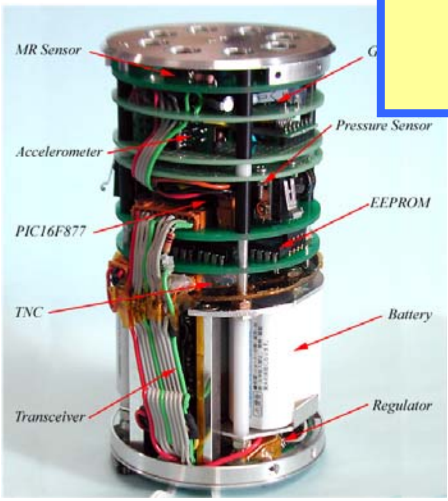
Educational Significances of CanSat/Micro/Nano/Pico-Satellite Projects

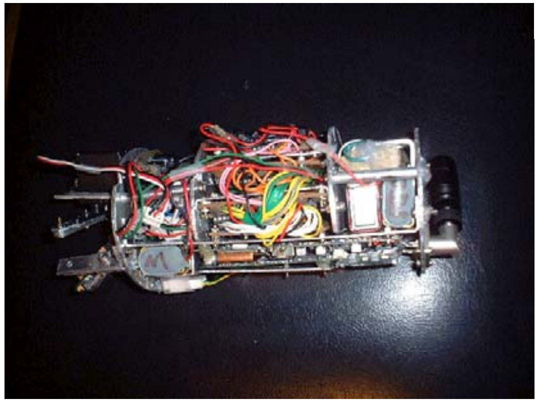
- ***Practical Training of Whole Cycle of Space Project***
  - Mission conceptualization, satellite design, fabrication, ground test, modification, launch and operation
  - Know <u>what is important</u> and what is not.
- ***Importance for Engineering Education***
  - Synthesis (not Analysis) of an really working system
  - <u>Feedbacks from the real world</u> 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

- ***Also contributions to other technology areas !***

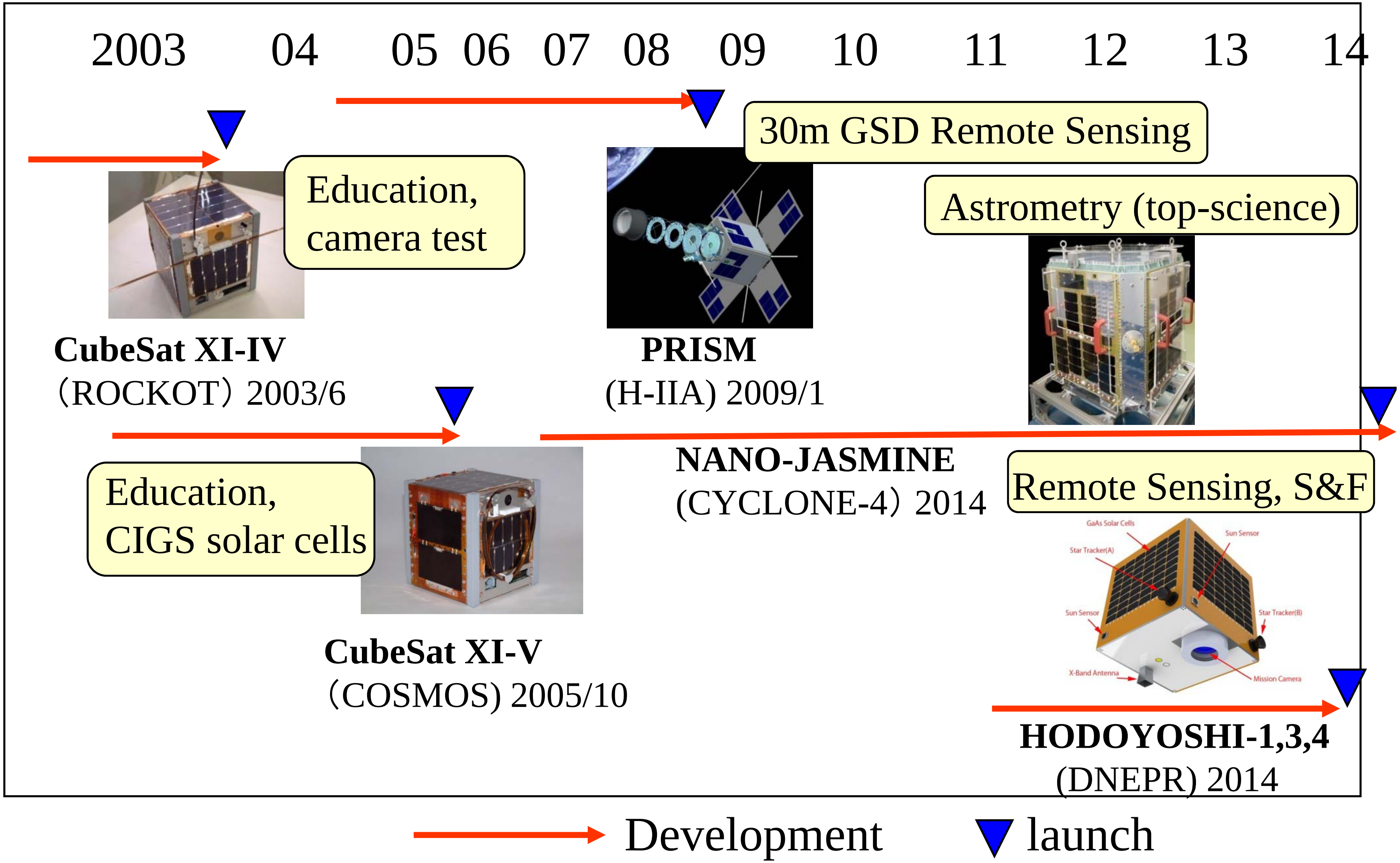
Training step: CanSat 1999-now







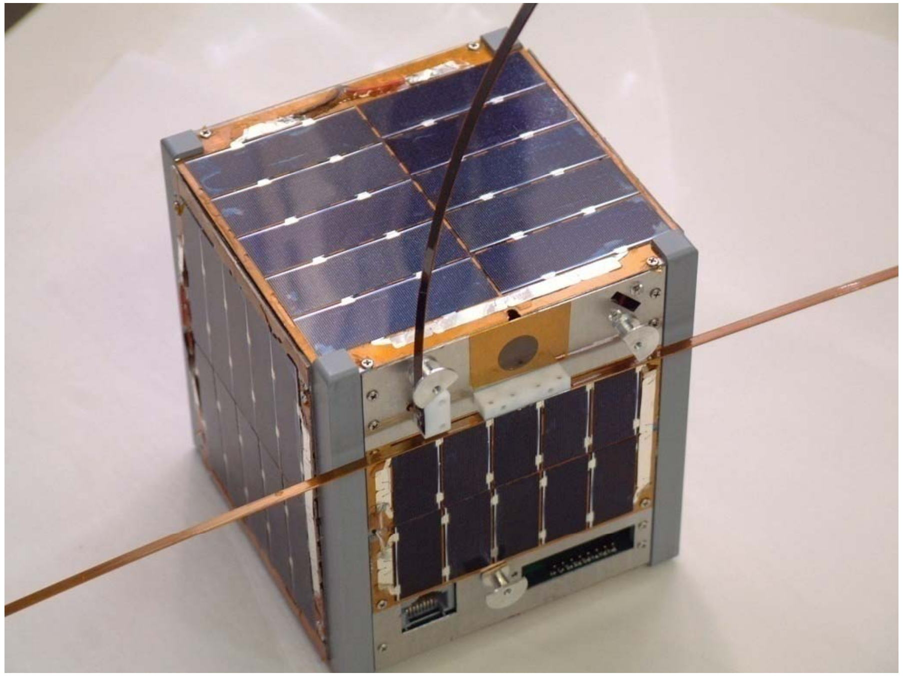
University of Tokyo's History of Nano/pico-satellite Developments



CubeSat “XI-IV (Sai Four)”

Mission: Pico-bus technology demonstration in space, 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

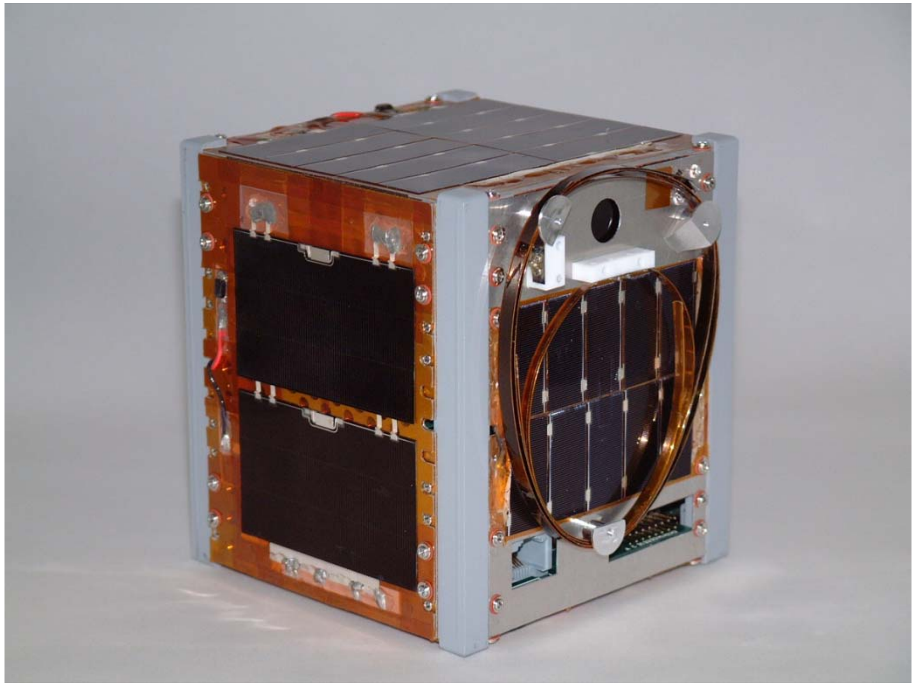


Captured Earth Images and Distribution to Mobile Phones

CubeSat "XI-V (Sai Five)"

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



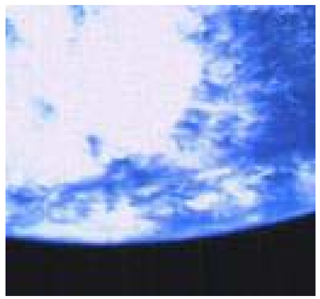
SSETI-EXPRESS

T-POD deployment System

Deployed from SSETI-EXPRESS in space

JAXA/NEDO CIGS Solar Cells

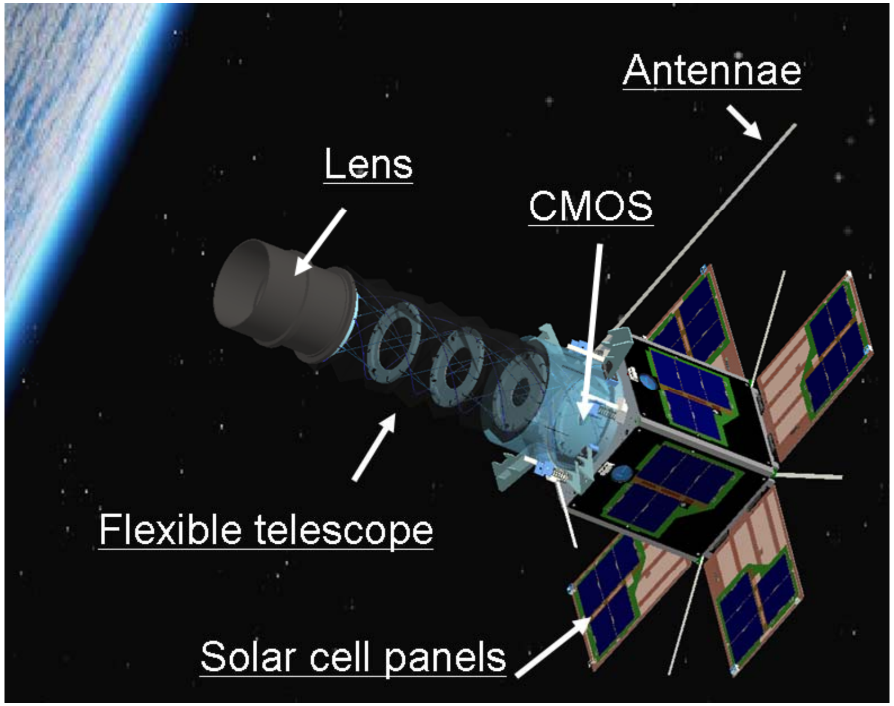
Captured Earth Images

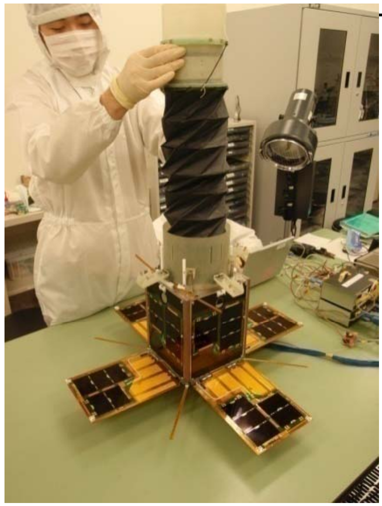


PRISM “Hitomi”

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

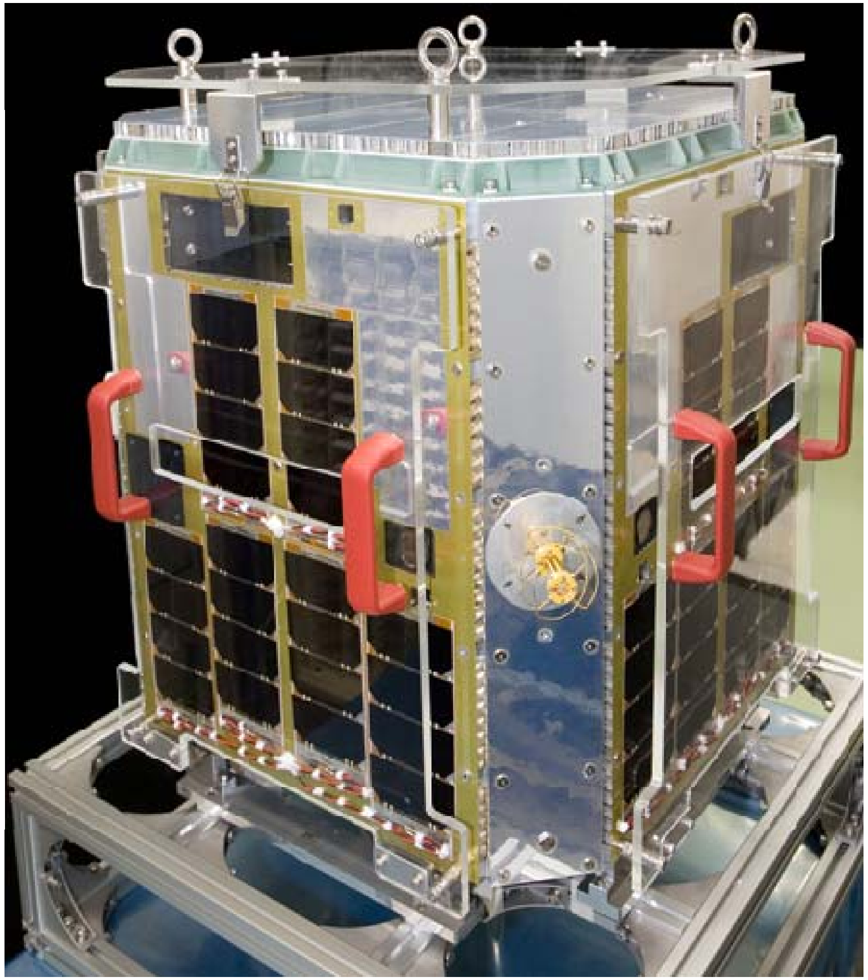
Kita-Kyushu (Japan)

Wide Angle Camera

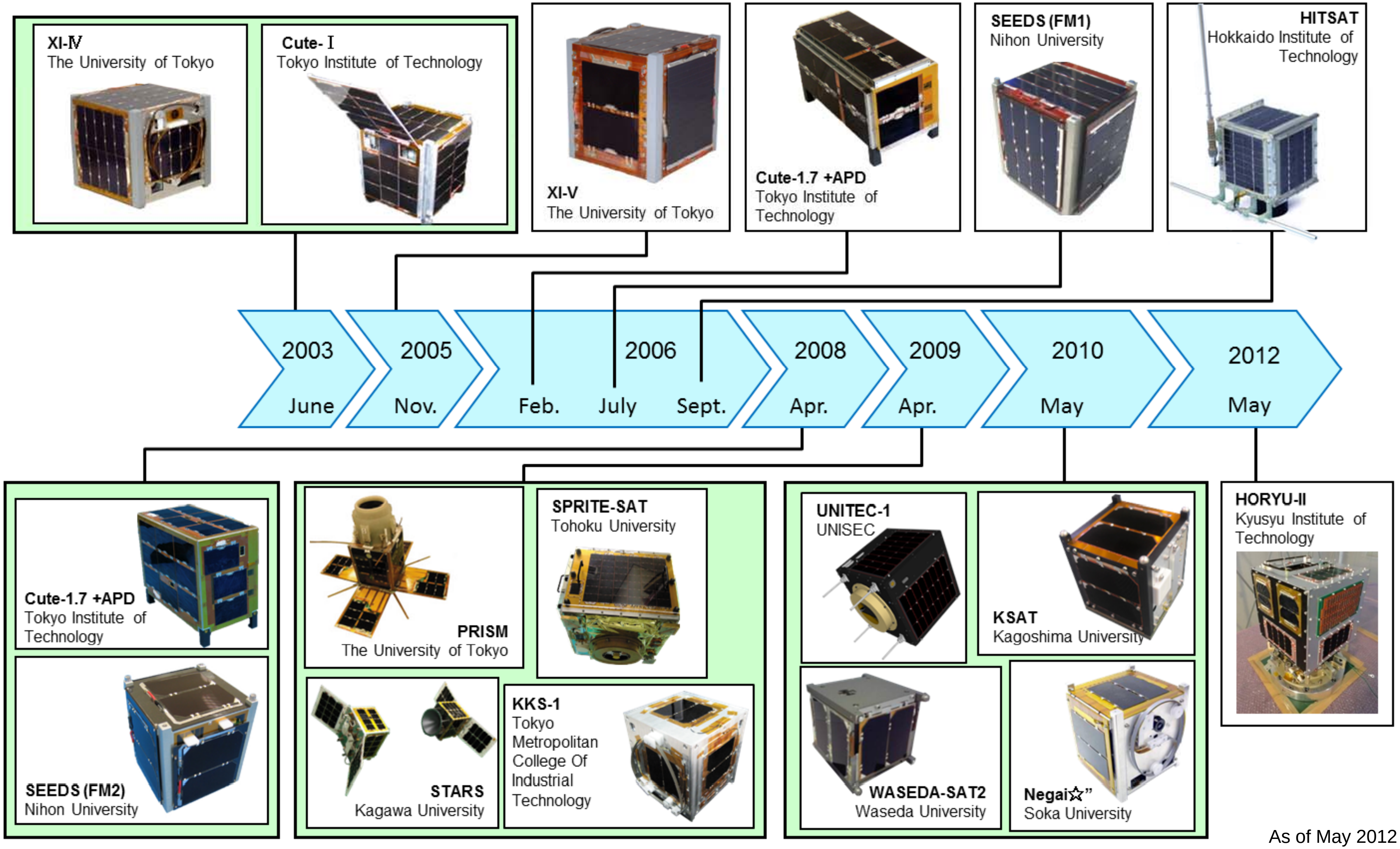
Nano-JASMINE

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: Cyclone-4 (planned within 2014-15) from Alcantara Launch Site

Size	50 [cm-cubic]
Weight	33 [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



Satellites made by UNISEC Universities



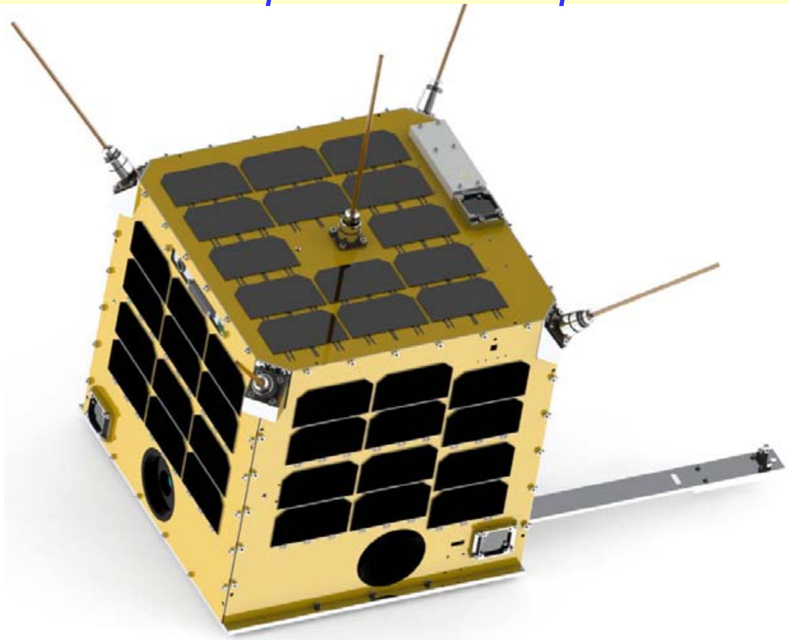
As of May 2012

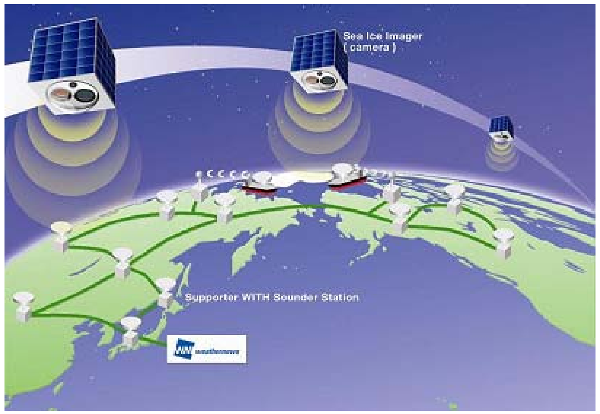
WNISAT-1

Missions: Iceberg observation in Arctic Ocean, Atmospheric Observation (CO_2)
Developer: AXELSPACE, Weather news Inc.
Launch: DNEPR (2012) (planned)

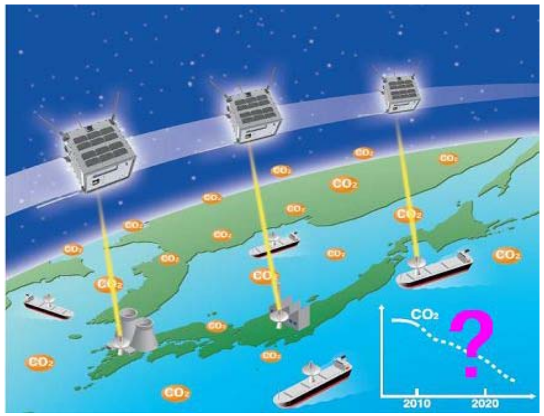
Please visit: http://www.axelspace.com

Size	27x27x27[cm]
Weight	15 [kg]
Attitude control	3-axis stabilization with STT, SAS, Magnetometer, Gyros RW, magnetic torquers
OBC	FPGA
Communication	UHF (max 38.4 kbps)
Camera	Visible & NIR, GSD 500m
Laser	CO_2 absorbed (1.55μm)
Mission life	2 years





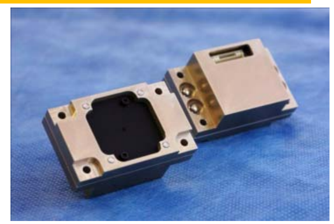
Global Iceberg Monitoring



Experiment of CO_2 density measurement

Components by AXELSPACE


Star Sensor (AxelStar)


Coarse Sun Sensor (AxelSun)

More info available at our website!

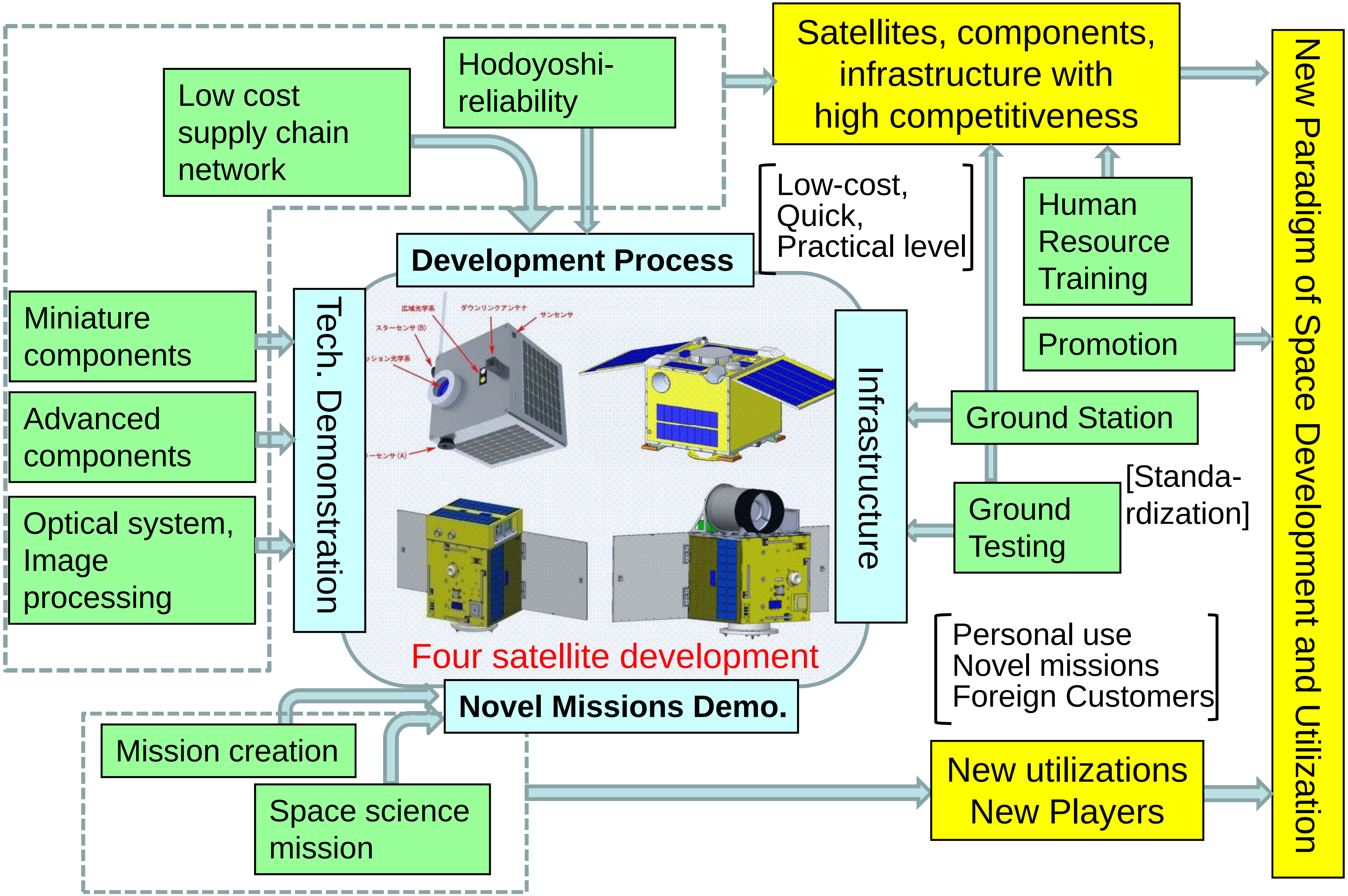
Outcomes of University Satellite Projects

- Significant educational effects have been proved !!
- Can be applied to even “really useful” missions;
  - Earth observation, Space sciences
  - Entertainment, contents creation, education…
- Possibility of “business use” by especially non-government customers
- For those objectives, we should improve in many directions;
  - Reliability (but without so much additional cost)
  - Component technologies in many areas
  - Development process (especially the ground tests)
  - Utilization techniques and user community generation

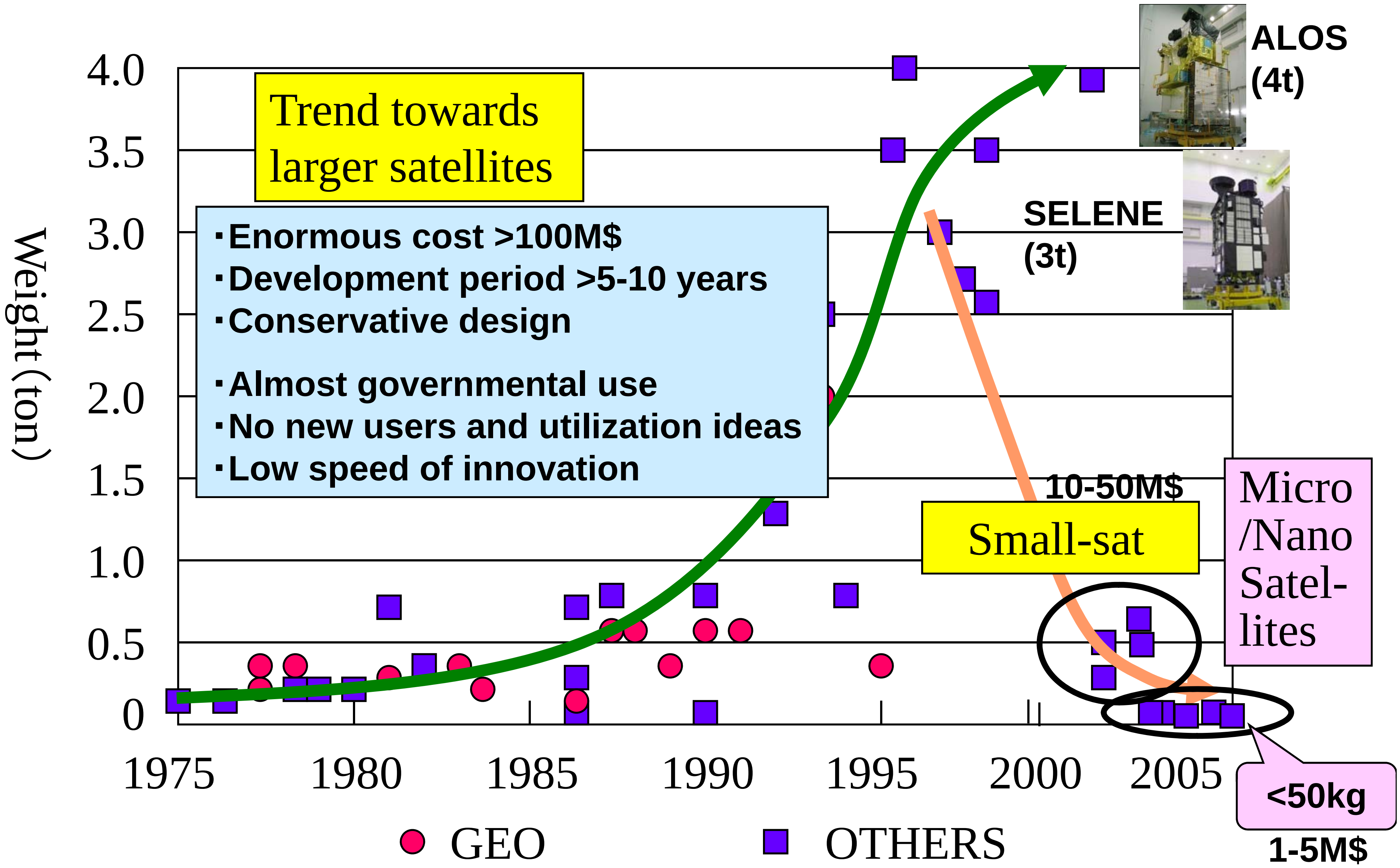
Governmental "First" Program
"Hodoyoshi-project" (2010-2014)

- Reliability concept for micro/nano/pico-satellites
  - "So-so and not expensive (Hodoyoshi)" reliability
    (compromise between cost (workload) vs. reliability)
- Component technology development
  - Should solve "size and power problem"
- Development process innovation
  - Software architecture
  - Ground test, etc.
- Create novel applications and use communities
  - Non-government users as individuals, companies, local government, research institute can seek for their interest

Overall R&D Structure of Hodoyoshi-PJ



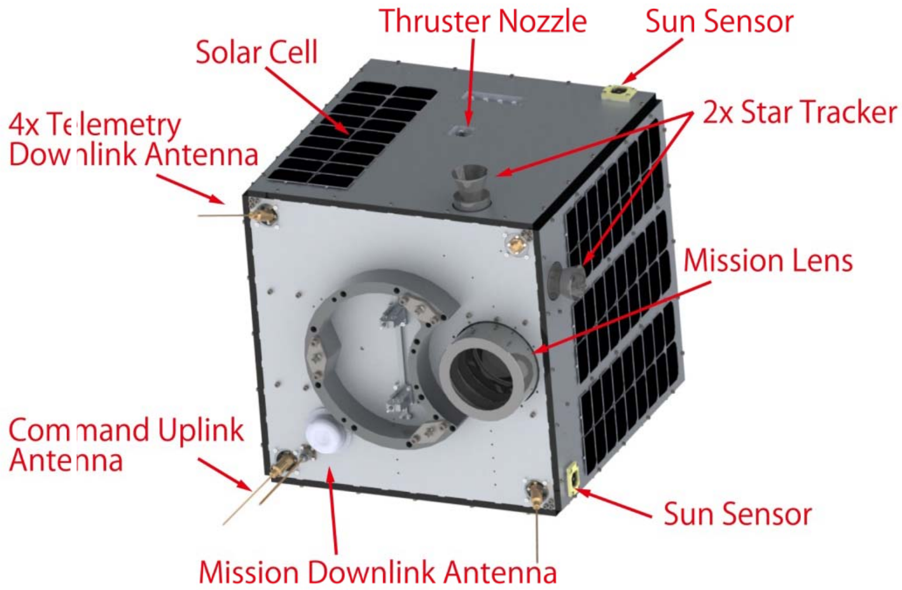
Motivation: Problem of Mid-large Satellites



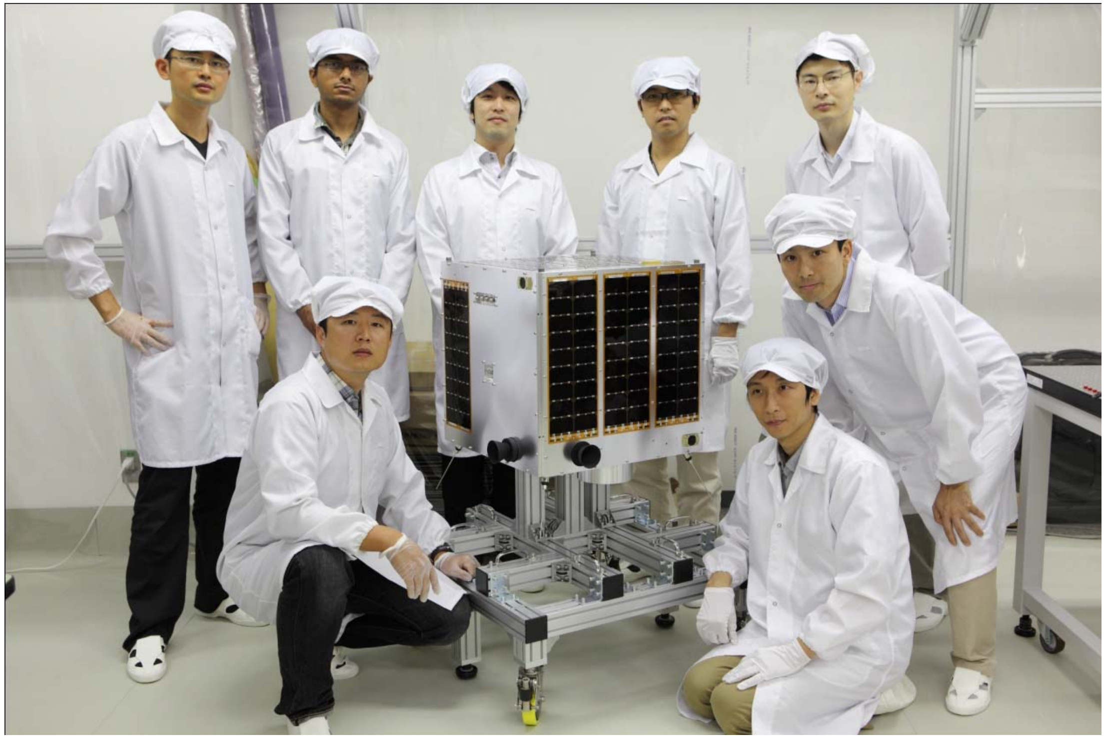
HODOYOSHI-1

Mission: Earth Remote Sensing (6.7m GSD, 4 bands: RGB & NIR)
Developer: AXELSPACE, University of Tokyo, NESTRA
Launch: DNEPR in 2012

Size	50 [cm-cubic]
Weight	50 [kg]
OBC	FPGA
Communication	UHF, X (max 20 Mbps)
Mission life	2 [year]
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)
- IFOV	24.3 x 16.2 km (500km alt.)
- Bands(SNR)	B(103), G(119), R(84), NIR(63)
- Onboard storage	8GB (~100 compressed images)



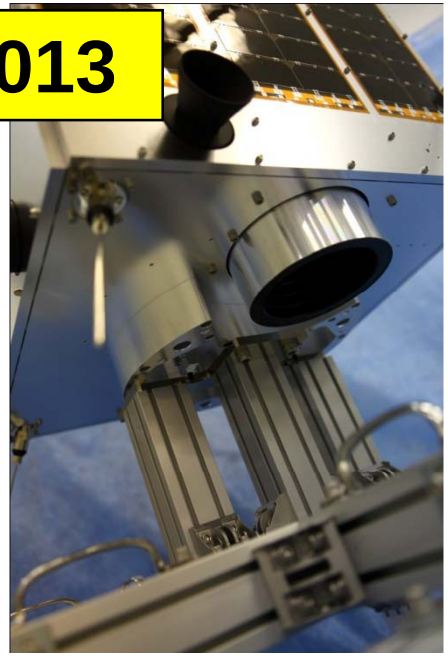
Optical Camera (6.7m@500km)
developed by Genesia Corporation

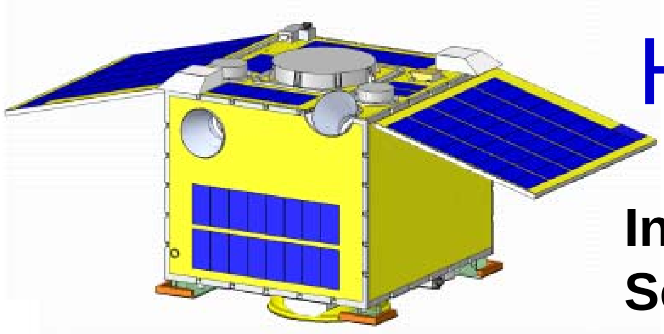


Hodoyoshi-1 completed in early 2013

DNEPR Rocket(at Ukraine)

6.7m GSDO
Refraction Optics





HODOYOSHI-2（RISESAT)

International Space Science Missions

Size:
50cm
55kg

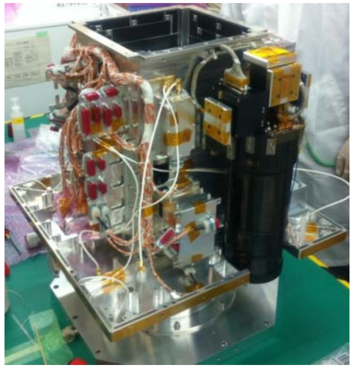
Comm:
S-band
38.4kbps
X-band
2Mbps

Power:
100W

ACS:
<0.1°

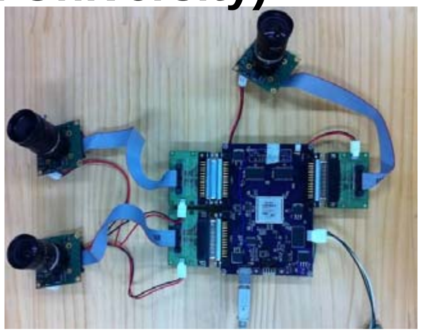
Rocket:
H-IIA (TBD)

High Precision Telescope- HPT (Taiwan/Vietnam)



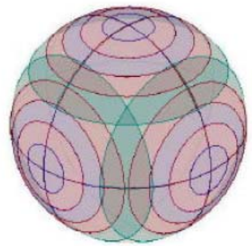
Meteor counter - DOTCam (Taiwan(NCKU))

Ocean Observation Camera - OOC (Tohoku University)

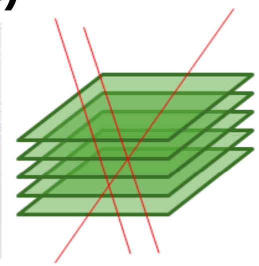


Camera Instruments

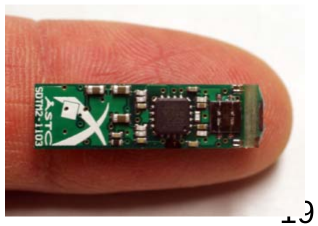
TriTel – 3D Dosimeter (Hungary)



TIMEPIX – Particle counter (Czech)



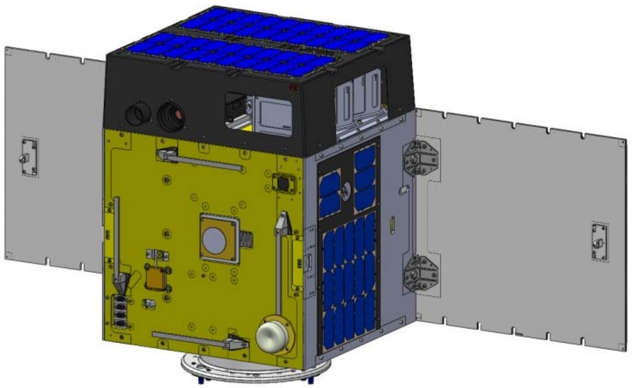
SDTM – MEMS Magnetometer (Sweden)



Sensor Instruments

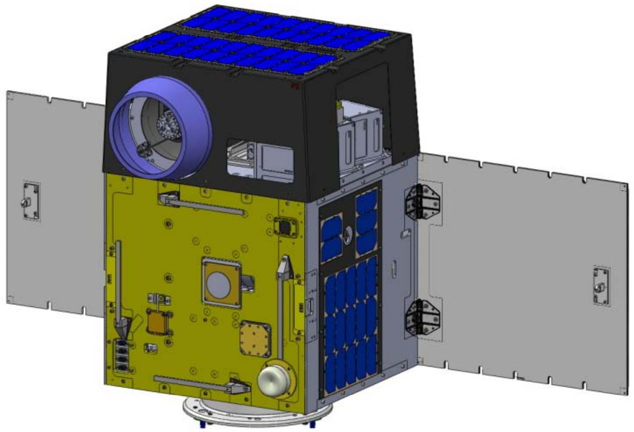
HODOYOSHI-3 & 4

Hodoyoshi-3



Based on a Standard bus

Hodoyoshi-4



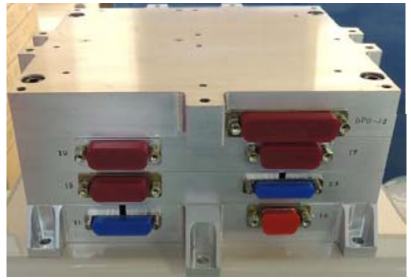
Rocket: DNEPR launch in early 2014

	Hodoyoshi-3	Hodoyoshi-4
Size	0.5×0.5×H0.65m	0.5×0.6×H0.7m
Weight	60kg	66kg
Orbit	SSO. 600km, LTAN 10am～11am	
ACS	Earth pointing, 3 axis stabilization	
Power	Power generation: max 100W Power consumption: average 50 W Bus voltage: 28V, 5V Battery: 5.8AH Li-Ion	
Commu-nication	H/K and Command: S-band uplink:4 kbps, downlink:4/32/64 kbps Mission data downlink: X-band 10Mbps (100Mbps to be tested on Hodoyoshi-4)	
Orbit control	H_2O_2 propulsion	Ion-thruster (Isp: 1100s)
Missions	Mid-resolution optical camera GSD: 40m & 200m	High-resolution optical camera GSD:5m
	Store & Forward Hosted payloads (10cm cube x 2) Hetero-constellation experiment	

Component/software technologies Development

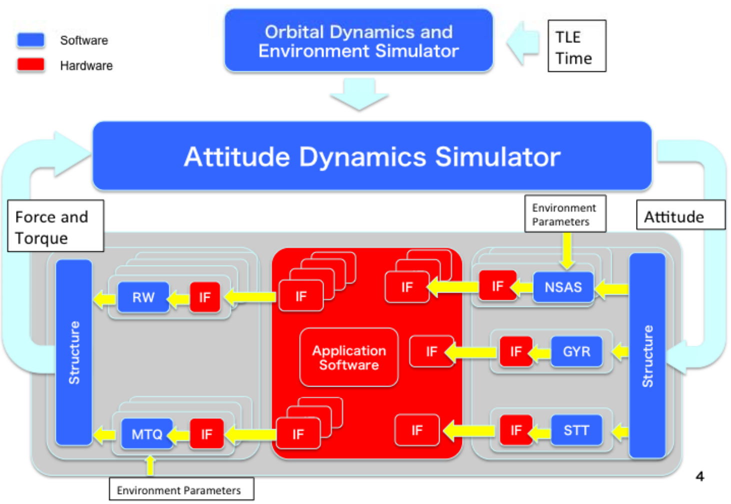
Components under development (example)

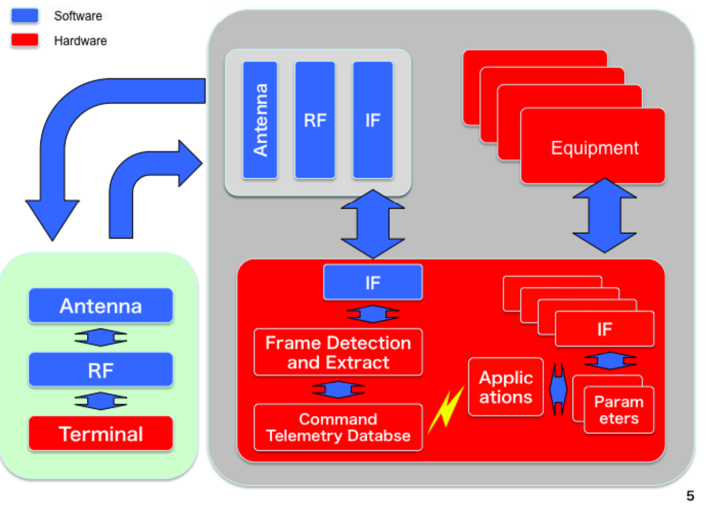
- Radiation-hardened SOI-SoC onboard computer
- Software architecture (SDK, HILS, etc.)
- Optical camera with 2.5 - 200m GSD
- Li-Ion battery and power control unit
- Low-shock lock/release & deployable mechanism
- High speed and versatile data handling unit
- High speed, low power RF transmitter （>100Mbps)
- Electric propulsion system (Ion thruster)
- Attitude control system for micro/nano-satellite
  - Fiber optical gyro, Reaction wheel, CMG, etc.
- Debris mitigation device (deployable membrane)
- Optical communication system (with NICT)

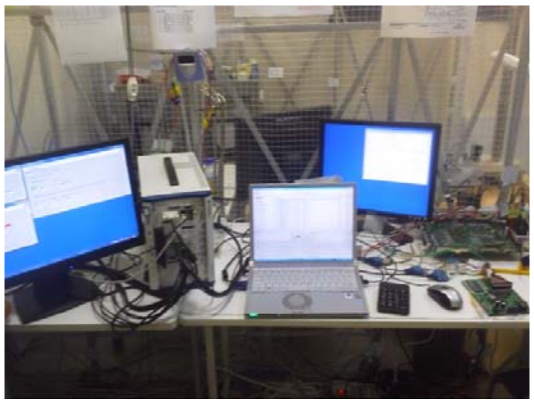


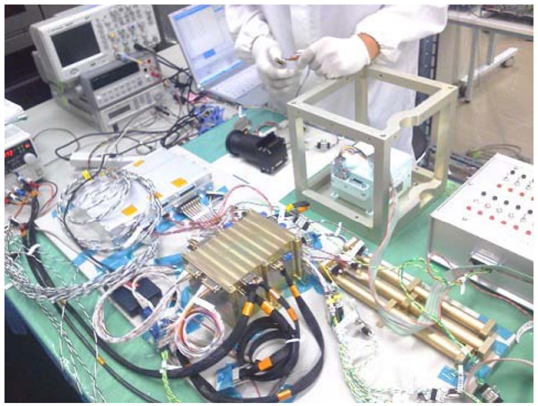
Software: “Hodoyoshi SDK”
- Hardware in the Loop and Verification System -

- Software verification is essential to achieve software reliability.
- We developed hardware in a loop OBC software verification system.
- In the verification system, the performance and interface of the peripheral equipment is simulated by the PC simulator, and closed-loop simulation using a real OBC can be realized.



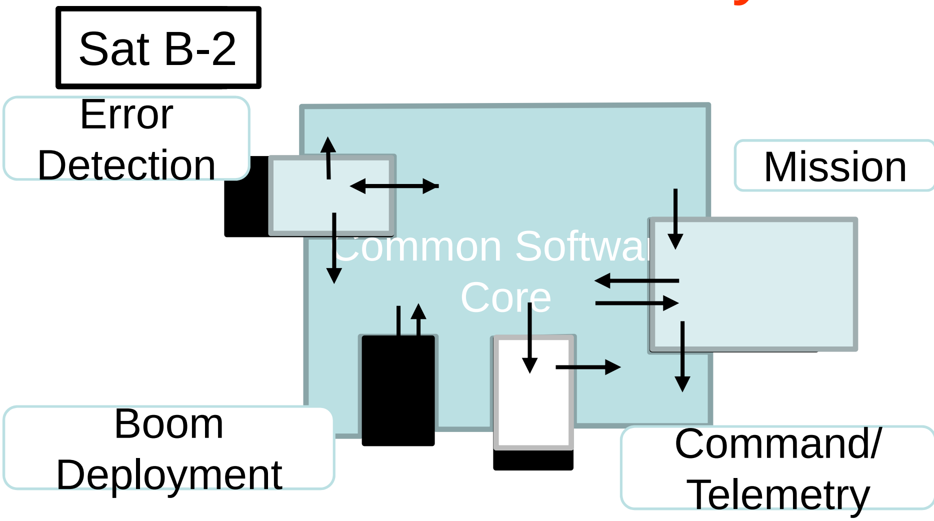


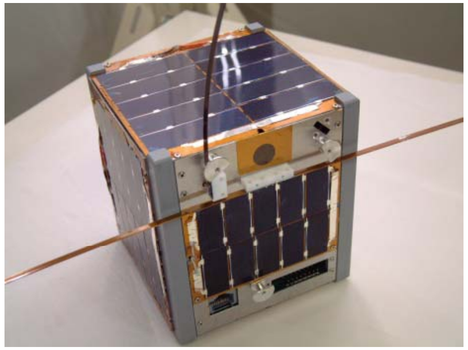




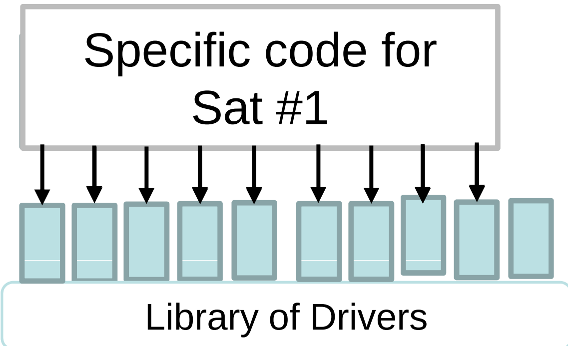
Framework and Driver Library in Hodoyoshi SDK

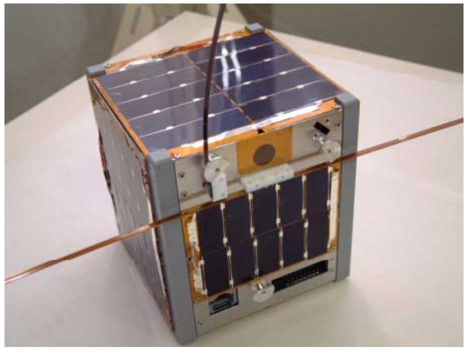
- Framework Software System





- Driver Library



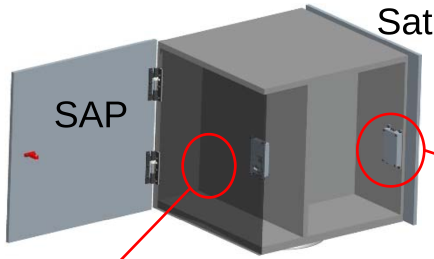


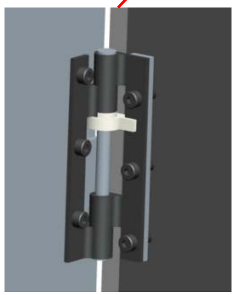
Deployable Structure

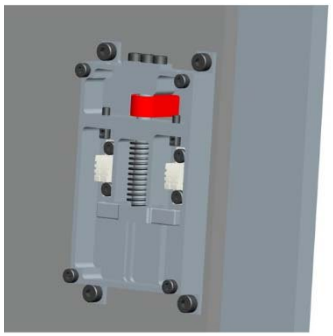
Simple and reliable devices for deployable structure

- Simple and reliable hold-release mechanism
- Latchable hinge
- Will be verified in space by “HODOYOSHI” #3 and #4 satellite

Satellite main structure

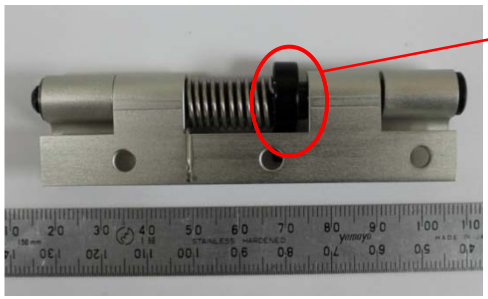


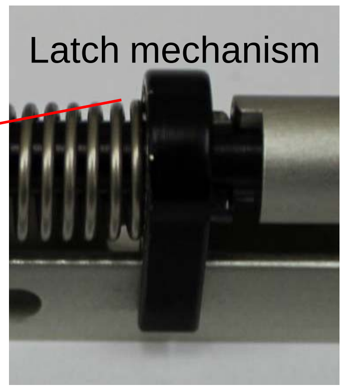




HRM (wire-cut type)

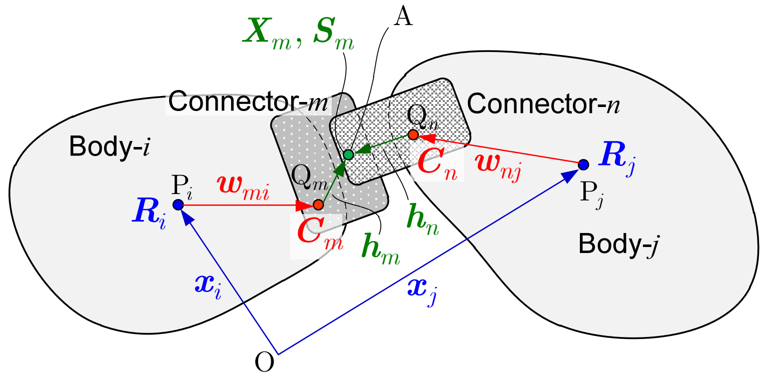
Latchable hinge





Theoretical estimation of performance of deployable structure

- Estimation of shape accuracy after deployment (for high-precision deployable structure)
- Estimation of smooth deployment



Constraint condition for each joint (position and attitude)

$$\boldsymbol{f}_{mn} = \left[\boldsymbol{x}_i + \boldsymbol{R}_i \cdot (\boldsymbol{y}_{mi} + \boldsymbol{T}_{mi} \cdot \boldsymbol{z}_m)\right] - \left[\boldsymbol{x}_j + \boldsymbol{R}_j \cdot (\boldsymbol{y}_{nj} + \boldsymbol{T}_{nj} \cdot \boldsymbol{z}_n)\right] = \boldsymbol{0}$$

$$\boldsymbol{g}_{mn} = \boldsymbol{R}_i \cdot \boldsymbol{T}_{mi} \cdot \boldsymbol{Q}_m - \boldsymbol{R}_j \cdot \boldsymbol{T}_{nj} \cdot \boldsymbol{Q}_n = \boldsymbol{0}$$

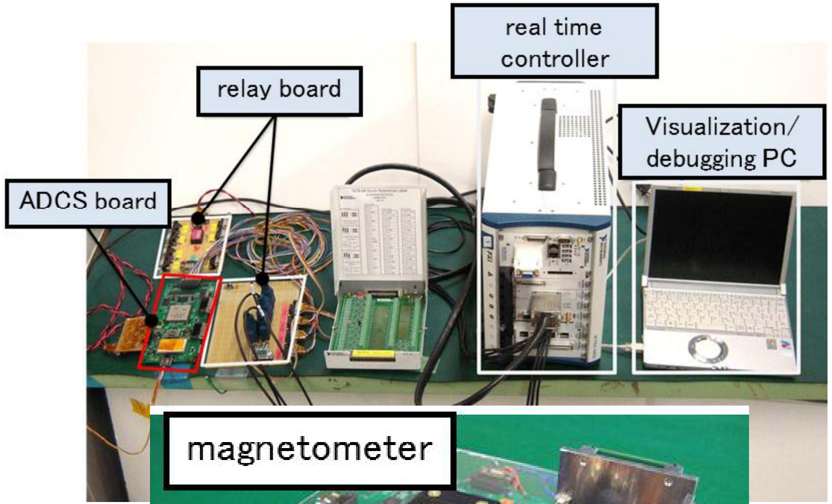
→ Relation between deviation of design parameter **u** and state vector ξ

$$\boldsymbol{H} \cdot \delta \boldsymbol{u} + \boldsymbol{L} \cdot \delta \boldsymbol{\xi} = \boldsymbol{0}$$

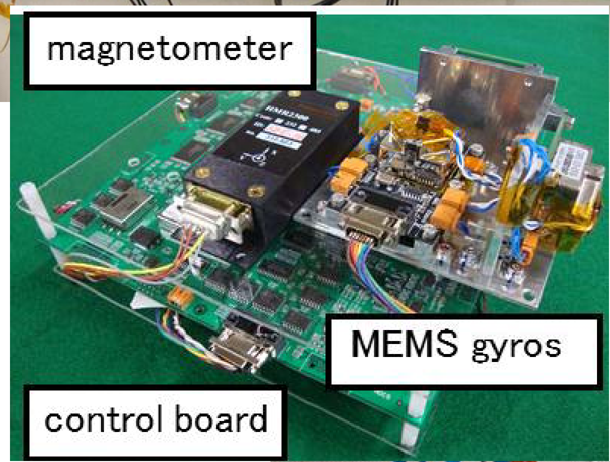
→ Estimation of performance

CMG and Advanced Ground Test Methods

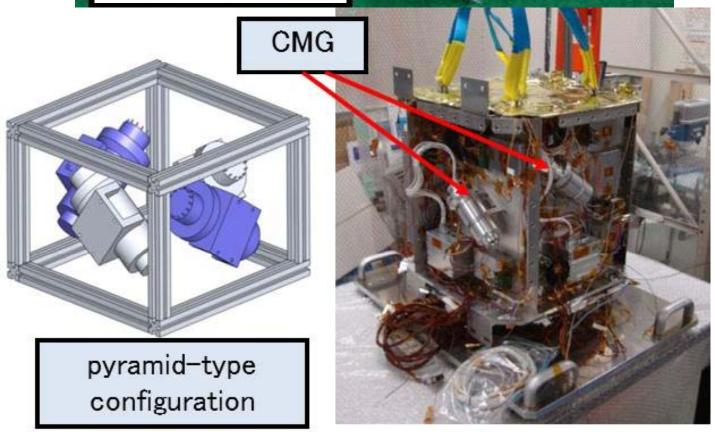
1. Design and Development of Integrated Simulator to Verify Attitude Determination and Control System for Advanced Small Satellites



2. Design and Development of small CMG for Large Torque Generation and High-rate Attitude Maneuver



3. Integrated and Environment Tests of Attitude Determination and Control System



Satellite Optical System

Athermal Apochromatic Optics

Robust to temperature changes
Swath 27.8km　GSD 6.7m
4 bands (RGB+NIR)、S/N > 100

For Hodoyoshi-1

$$\beta_{lens} = \alpha_{metal} = \alpha_{glass} + \left(dn/dT\right)/\left(n-1\right)$$

Selecting appropriate optical material and its combination can reduce optical distortion made by Thermal expansion of support structure

Optical Receptor

CCD with Precise Optical Filter
Push Bloom　type
NIR-band for Super resolution

Optical Filter and Line CCD

NIR Filter

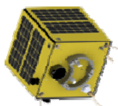
RGB CCD

Mono CCD

Visible Image

NIR Image

4 band CCD Detector System



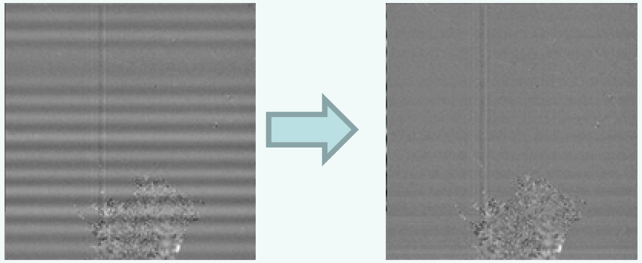
Onboard Hodoyoshi-1 to be launched in early 2014

Advanced Optics & Image Data Processing

Image Data Processing

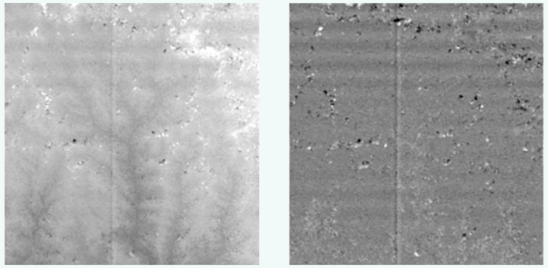
Modeling of satellite and telescope
Elevation model using parallax
Distortion correction for attitude jitter

Stripes Show jitters



Correction of attitude jitter

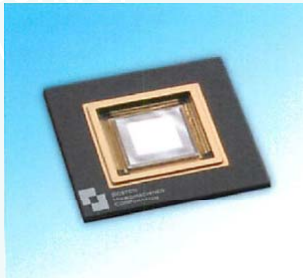
Elevation model for Mt. Everest



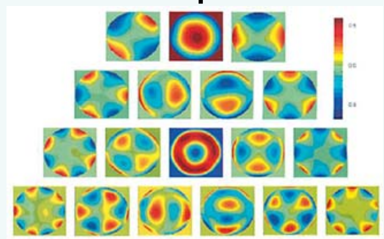
Elevation model and attitude jitter

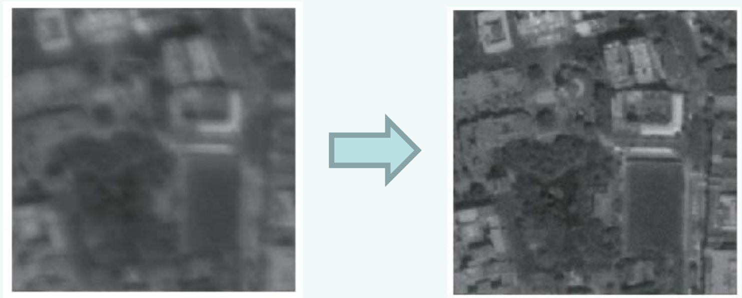
Adaptive Optics

Correction of distortion in optical system
Optimization using multi actuator control



Deformable mirror and its pattern





Resolution enhancement

Advanced solutions for future optical observation

Propulsion system: Hodoyoshi-1 and 3

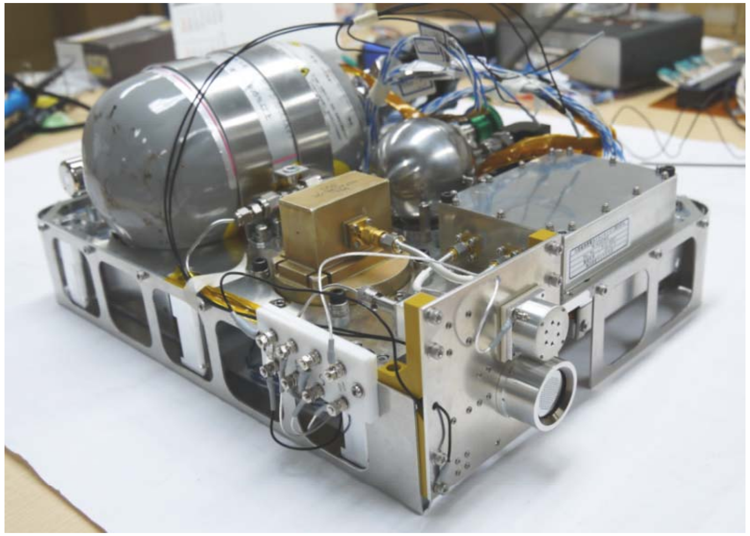
- Hodoyoshi-3 will employ non-toxic H_2O_2 propulsion system which is also used in Hodoyoshi-1
- This propulsion system is capable of 2,400 Nsec of total impulse, that can achieve 180 km perigee descent maneuver from 600 km circular orbit for 50 kg satellite

Picture of the Engineering model

Item	Specification
Propellant	**H_2O_2**
Thrust	**500mN**
Specific thrust	**80 sec**
Propellant weight	**2.5kg**

Miniature Ion-Propulsion System（MIPS）

MIPS Engineering Model

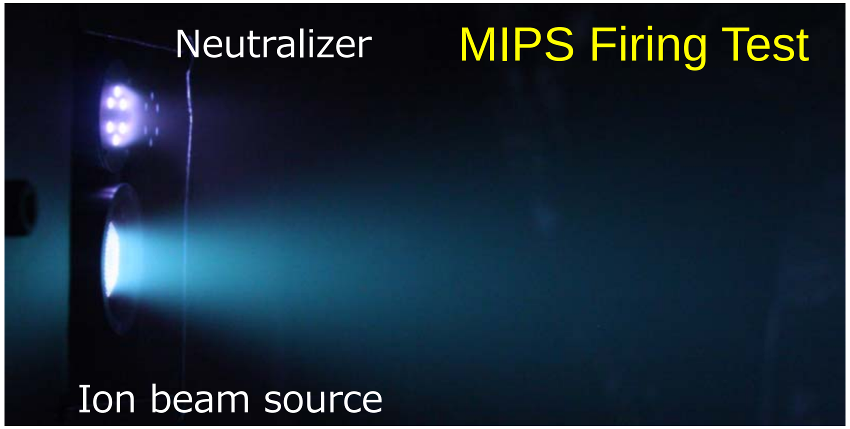


KEY TECHNOLOGIES

- Low power(1 W)plasma generation by microwave
- High efficiency Ion beam through miniature grid
- Optimization of neutralizer

REMARKS

- World first Ion-thruster system for micro-satellites
- Modular type propulsion system
- High orbit transfer capability (>400km for 50kg)



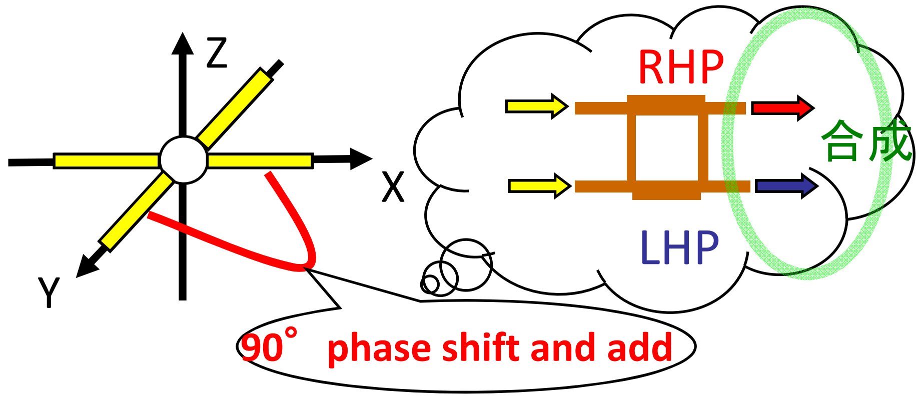
Onboard Hodoyoshi-4 (2014 launch)

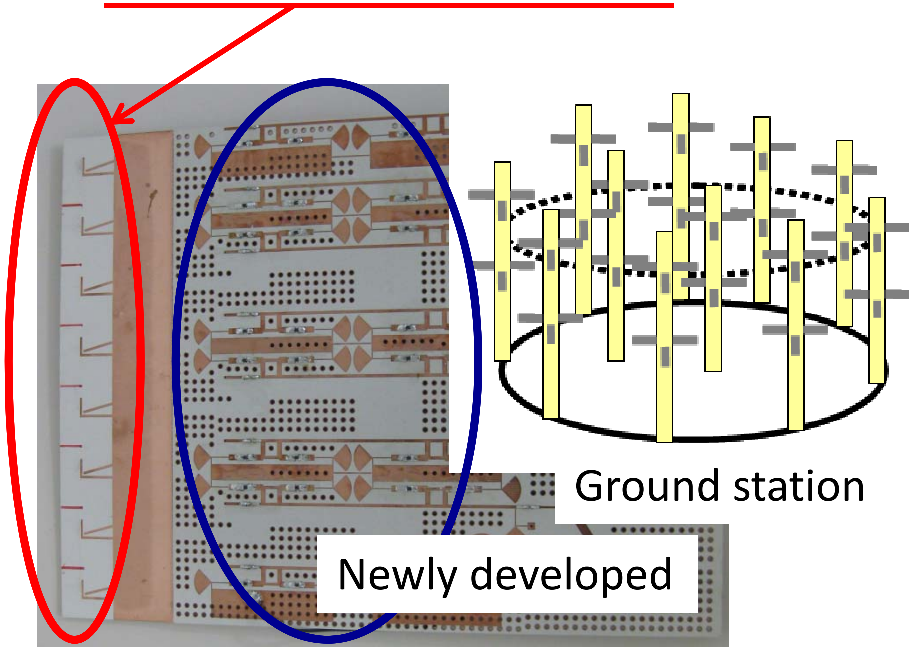
MIPS specifications	
Weight	**8 kg (incl.1kg Xe)**
Size	**39×28×16cm**
Power consumption	**30 W (TBD)**
Thruster	**300 μN**
ISP	**1200 s**
Total impulses	**12 kNs**
Total ΔV	**240 m/s (50kg S/C)**

Ground station system for Micro-satellite operation

1）Ground station using active phased array antenna system

- Antenna element development for omni-directional active phased array antenna
- Integrated printed board of pre-amp, phase shifter, mixer, and adder





8 element array antenna board

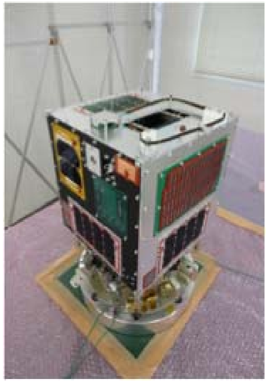
2）Ground station with parabola antenna

- UHF, S, C, X antenna
- Kyushu univ.(2.4m), Taiiki-cho(3.8m), ISAS, Tokai Univ(2.4m), and Fukui-tech (10m)
- Networking and intelligent ground operation

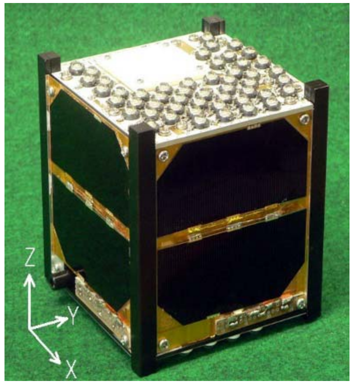
Ground Testing

Test Center at Kyushu Institute of Technology

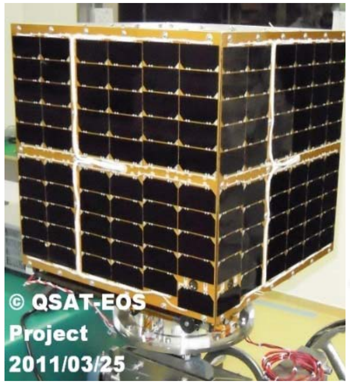
Concentration of Nano-satellite environment tests



HORYU2



FITSAT



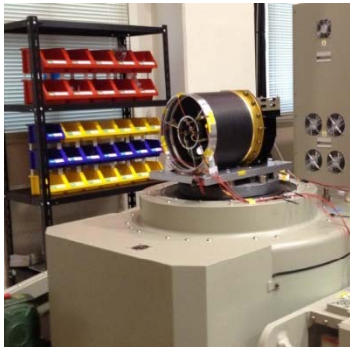
QSAT-EOS

STARS-II

UNIFORM

Outreach

(15 tests of components manufactured by small business)



Telescope for nanosatellite

Development of new test method

Rupture & Leak test

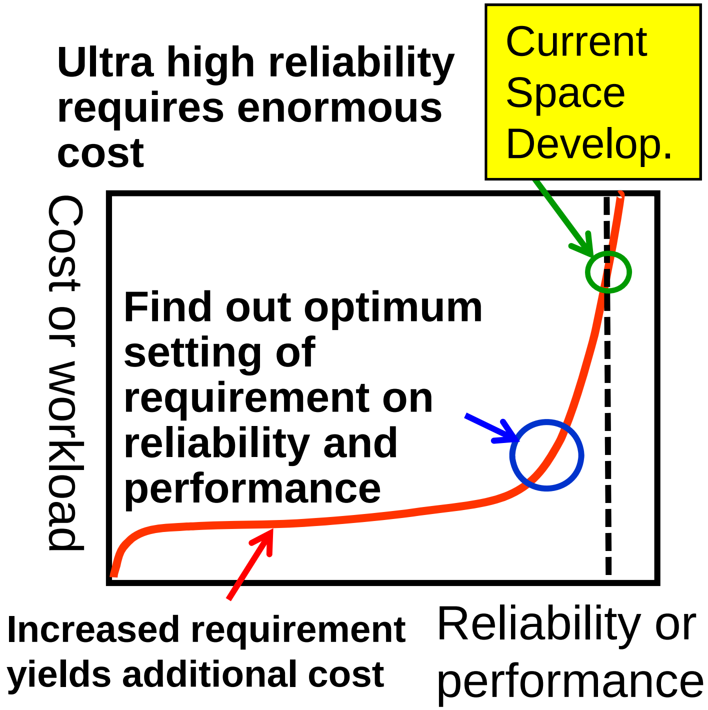
Single-event test

International Standardization

International standardization workshop

Hodoyoshi reliability (Reasonably reliable systems engineering)

Enlarge problem framework and search for total optimum solution with new DOF



Design strategy example

Athermal-Apochromatic design

1) <u>Factors really affecting satellite reliability</u>

○Reliability＝designed reliability_×
probability that the system behaves as designed

○"Context number" has been introduced to roughly Indicate the "complexity of the system" which degrade the second part

○If Context number is large or propagated to other subsystem, then the combinatorial explosion of context number degrades system reliability tremendously

2)<u>Design Strategy to reduce Context Number or cut the propagation of Context Number</u>

－Re-setting
－ Solar cells on all surfaces
－Thermal design with minimum node
－On-orbit tuning/reconfiguration
－Athermal design
－Under Voltage Control

3)<u>Efficient development process (Process approach)</u>

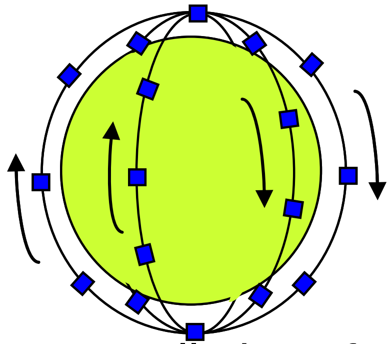
○Optimum distribution of workload
○Interface re-consideration with outside vendors
○Program level continual Improvement off reliability

Creation of Missions

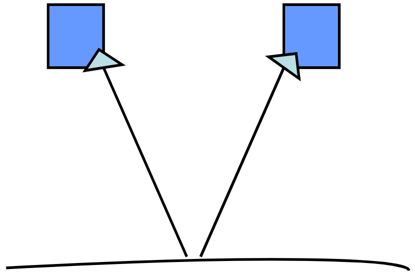
more to be discussed
in the 2nd day's panel discussion

Suitable Missions for Micro/nano-satellites

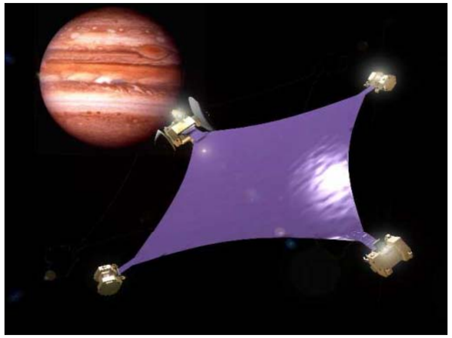
- Low-cost and small size realize satellite constellation
  - More frequent (ex. semi-daily) observation of the same areas
- Formation flight
  - Many scientific applications such as interferometer, multi-site observation, stereo vision
- "Personal Satellite" "My Satellite"
  - Novel ways of utilization including entertainment, education, contents, etc
  - Just like "PC and internet" innovation which has changed the world



Constellation of
a hundred satellites



Stereo Vision



"Furoshiki" satellite

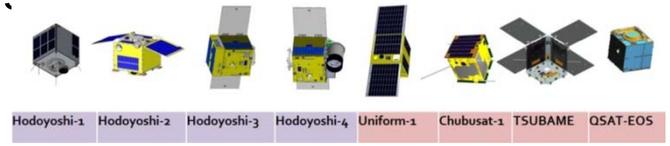
Monitoring Agriculture/Fishing/Forest

- Every day growth of crops, plants, etc.
  - To decide when to harvest wheat
  - To check health status of plants and trees
- Prediction of amount of crops
- Obtaining fields/forest management data
  - To detect not-used rice fields
  - To check usage of fields
  - To estimate tree types and volume of forest
- Search for fishing fields (by temperature, etc)
- Collection of water surface information
  - detection of red tide

Monitoring of 3.11 Catastrophe and Aftermath Response using a Constellation of Micro Observation Satellites
"Ukraine-Japan Collaborative Monitoring Project"

- *MOU for joint utilization of Hodoyoshi satellites was exchanged October 2010 between Ukrainian organizations under SSAU and University of Tokyo.*

- Taking the advantage of simple, low cost, short lead-time of the micro satellites, the University of Tokyo is building a satellite constellation including Hodoyoshi-1,2,3,4 that can quickly respond to national catastrophes for the monitoring of disasters an aftermath response.



- First meeting of joint Japan-Ukraine committee for the cooperation to advance aftermath response to accidents at nuclear power stations was held in Tokyo, July 26th 2012 by Ministry of Foreign Affairs, and the joint satellite observation program was discussed and welcomed.

- *Ministry of Education and Science (MEXT) started to support to this program.*

- Ukrainian Chernobyl monitoring specialists were invited to the University of Tokyo in February 2013

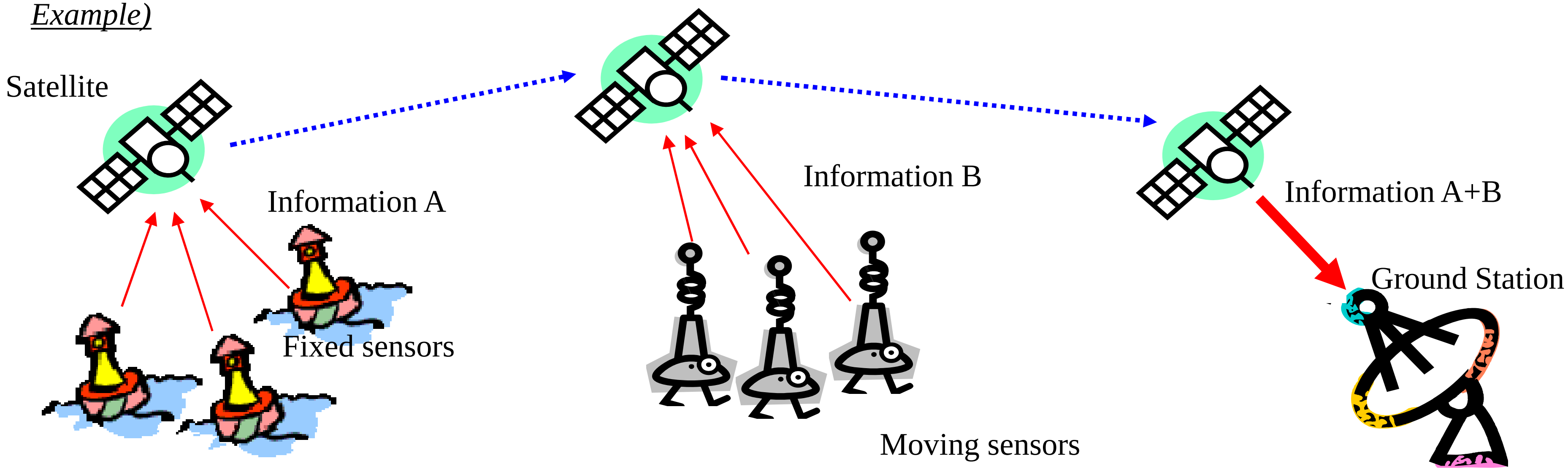
Hodoyoshi-3 & 4: Store & Forward

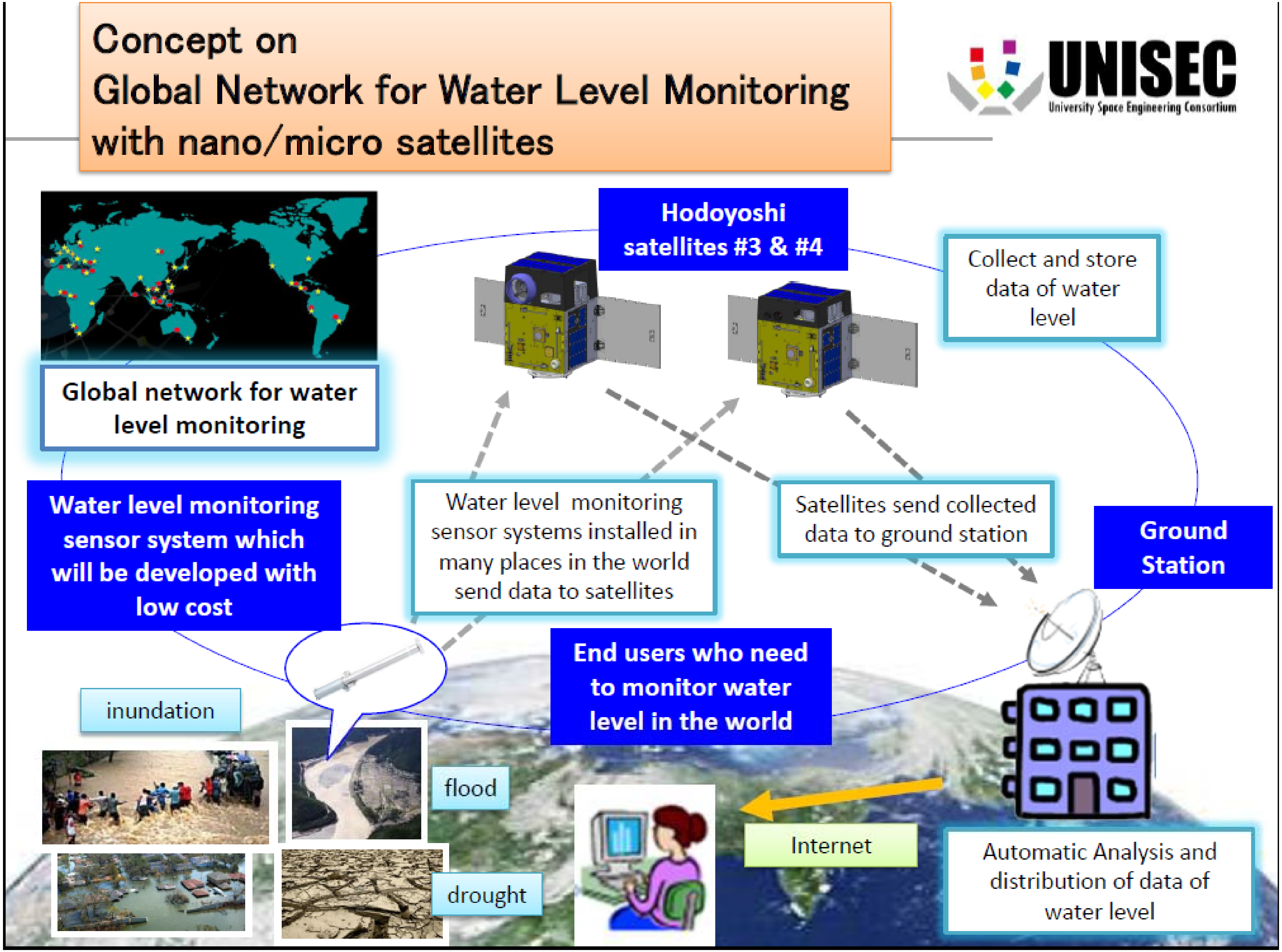
- UHF receiver onboard Hodoyohi-3 & 4 can collect data from ground Sensor Network (fixed points or mobile)

<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

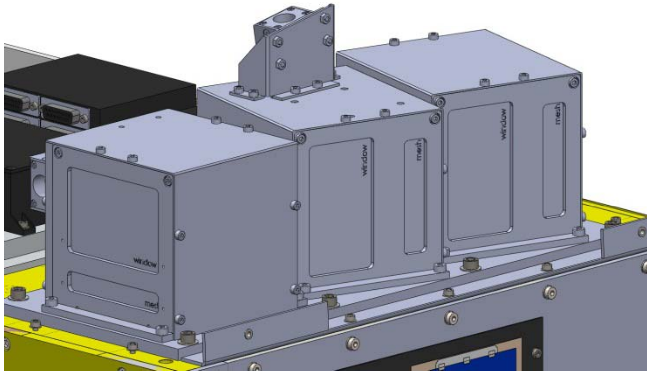
<u>Example)</u>

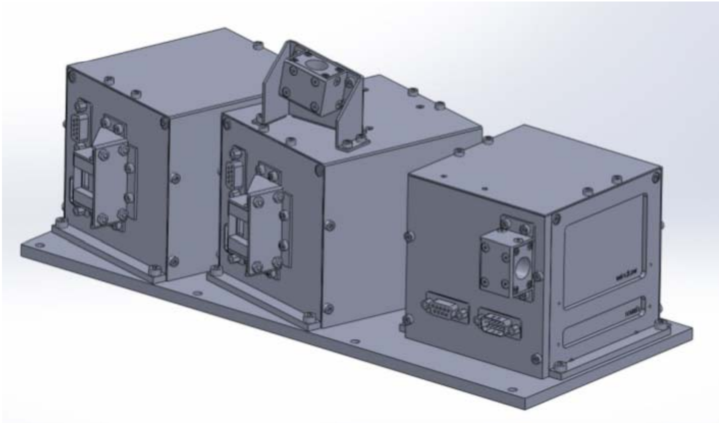




Concept on
Global Network for Water Level Monitoring
with nano/micro satellites
UNISEC
University Space Engineering Consortium
Hodoyoshi satellites #3 & #4
Collect and store data of water level
Global network for water level monitoring
Water level monitoring sensor system which will be developed with low cost
Water level monitoring sensor systems installed in many places in the world send data to satellites
Satellites send collected data to ground station
Ground Station
End users who need to monitor water level in the world
inundation
flood
drought
Internet
Automatic Analysis and distribution of data of water level

“Rental Space”: Hosted Payload (3 & 4)





- The “Hosted Payload” consists of 3 modules of 10cm cubic size (small cameras can capture inside)
- To provide the “orbiting laboratory” opportunity for enterprises and public
  - Space demonstration of new products
  - Space environment utilization (micro-gravity)
  - Space sciences, etc.

International Contributions

1)CanSat Leader Training Program (CLTP)

CLTP was established in 2011 to contribute to capacity building in space technology and to improve teaching methods in space engineering education.

- A one month course gives training through whole cycle of CanSat development including sub-orbital launch experiments
- Participants are expected to teach their students CanSat program in their countries
- Aiming at international CanSat education network

http://www.cltp.info

CLTP Participants

CLTP1 (Wakayama Univ. in Feb-March, 2011)
12 participants from 10 countries, namely Algeria, Australia, Egypt, Guatemala, Mexico, Nigeria, Peru, Sri Lanka, Turkey, 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, Nigeria, Namibia, Turkey, Lithuania, Mongolia, Israel, Philippines, Brazil

CLTP4 (Keio Univ. in July-August, 2013)
9 participants from 6 countries, namely Mexico, Angola, Philippines, Bangladesh, Mongolia, Japan

CLTP5(Planned) (Hokkaido Univ. in Aug.-Sept., 2014)

2) Mission Idea Contest (MIC)

for Micro/nano-satellite Utilization

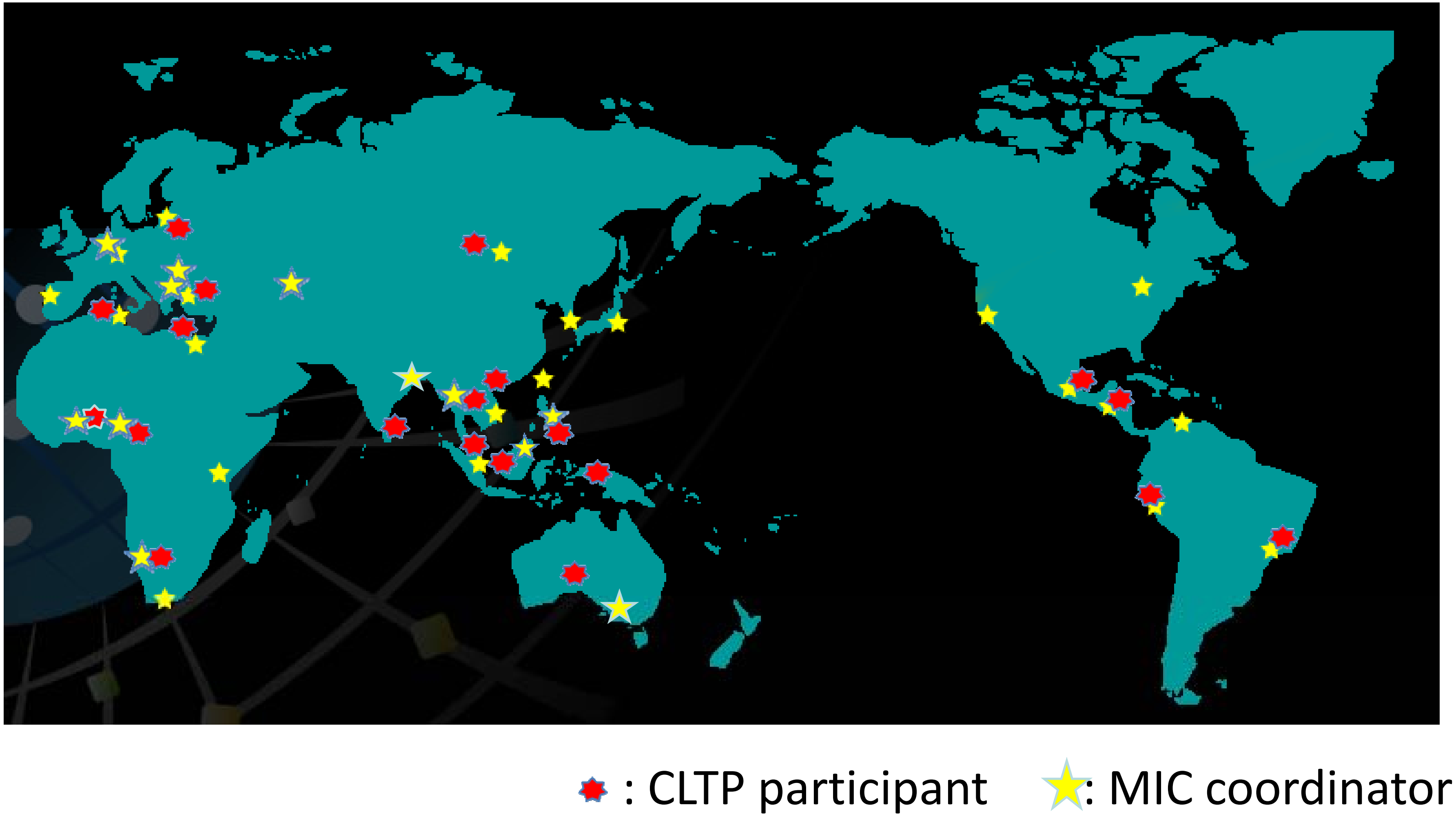
The 2nd
Mission Idea Contest
for Micro/Nano-satellite Utilization

- Objective: Encourage innovative exploitation of micro/nano-satellites to provide useful capabilities, services or data.
- Requirement: Propose innovative Mission Idea and Satellite Design

- Regional coordinators: 33 regions
- 1st : 62 proposals from 24 countries (2011)
- 2nd: 74 proposals from 29 countries (2012)
- **3rd: Pre-event: Nov.23, 2013 Final: 2014**

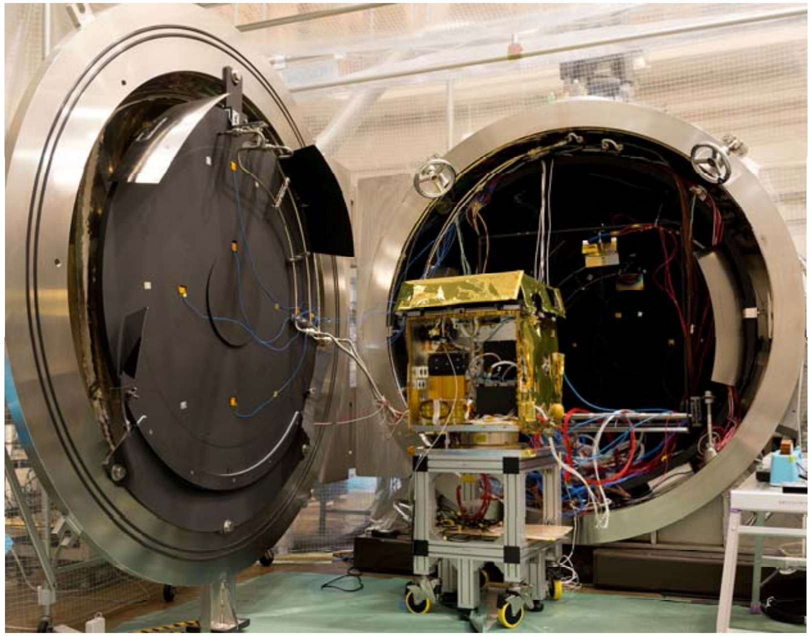
http://www.spacemic.net

Global network through Mission Idea Contest and CanSat Leader Training Program
(MIC:33, CLTP: 21 countries) 38 countries in total



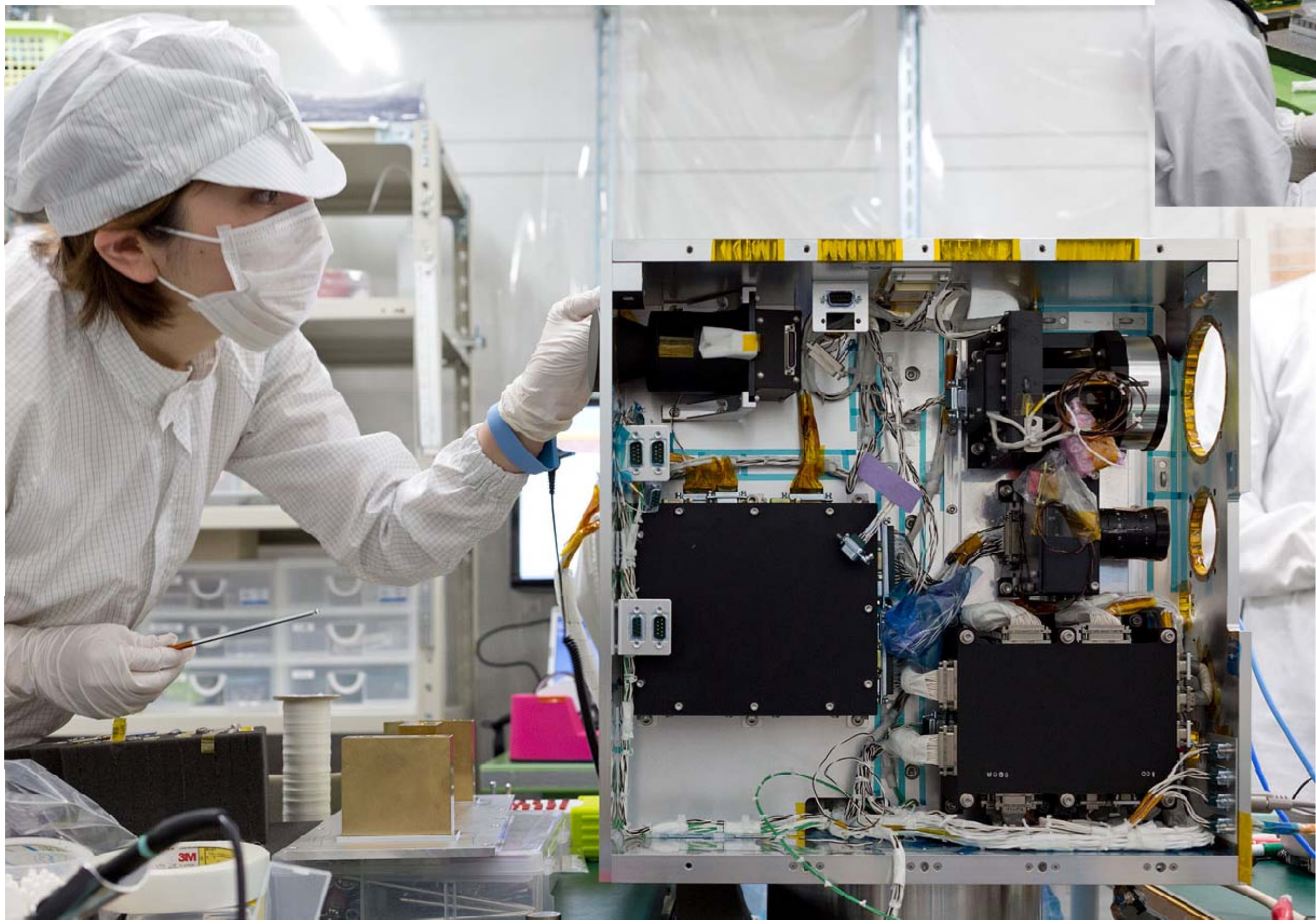
Images of Microsatellites Development

Vibration Test and Thermal Vacuum test of Hodoyoshi-3 EM



Images of Microsatellites Development

Uniform, Hodoyoshi-3, -4 FM Integration underway



Current Development Status

- Hodoyoshi-1: Completed
  - Launch in Feb 2014 by DNEPR
- Hodoyoshi-2: FM Phase
  - Launch by H-IIA (TBD)
- Hodoyoshi-3 & 4: FM Phase
  - Launch in March/April 2014 by DNEPR

Hodoyoshi-3&4 Table Sat

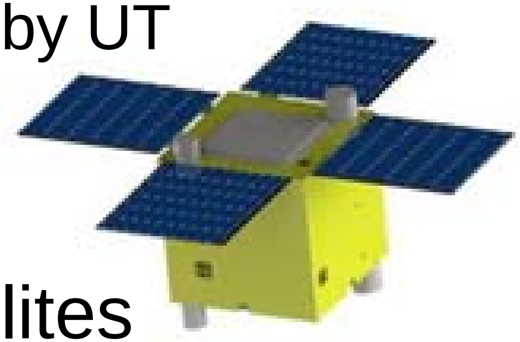
EM Integration

EM Vibration test

EM Thermal Vacuum Test

Next Phase of Hodoyoshi PJ

- **<u>Practical application phase</u>**
- Usage of Hodoyoshi-bus:
  - Vietnam ODA capacity building project: teaching more than 30 persons in 4 years by 5 Japanese universities
  - "PROCYON": deep space microsatellite by UT
  - Space science missions by JAXA (TBD)
  - Collaborations with private companies



- Missions realized by Hodoyoshi satellites
  - Measurement network using S&F
  - Fukushima environment monitoring mission
  - Rental space and image business
  - Disaster monitoring and other governmental missions