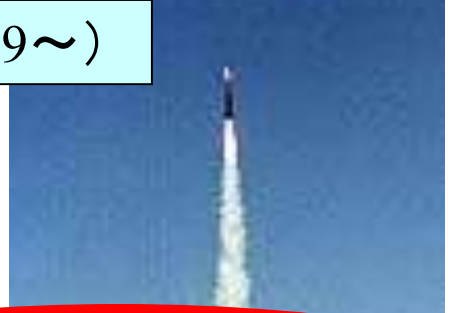
CanSat & Rocket Experiment(‘99～)



Hodoyoshi-1 ‘14

What is Important in Micro/nano/pico-satellites Development - From Engineering and Project Management Perspectives –

Shinichi Nakasuka
University of Tokyo

CubeSat 03,05

PRISM ‘09

Nano-JASMINE (TBD)

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

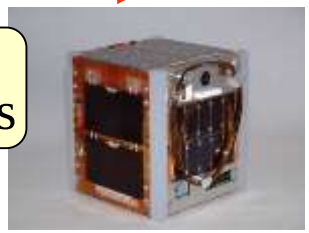
2003 04 05 06 07 08 09 10 11 12 13 14 15

[1] Education, Camera test

CubeSat XI-IV
(ROCKOT) 2003/6

World First CubeSat !

[2] Education, CIGS solar cells



CubeSat XI-V
(COSMOS) 2005/10

[3] 30m GSD Remote sensing

PRISM
(H-IIA) 2009/1

[8] Astrometry (top-science)

NANO-JASMINE
2017 (TBD)

[4][5][6] Remote sensing, S&F

HODOYOSHI-1,3,4
(DNEPR) 2014/6,11

[7] Deep space exploration

PROCYON
(H-IIA) 2014/12

[1]-[7]:Launched [8]: Waiting for launch

MDG (remote sensing, 50kg), TRICOM-1R (3kg, S&F), EQUULEUS (14kg, deep space) are being developed.

→ development ▼ launch

Start from simple CubeSat for educational objectives

Establishing UNISEC as University Community

1998～2010

University of Tokyo's CubeSat Project "XI"

"XI-IV"

2003.6.30 Rockot

"XI-V"

2005.10.27 Cosmos-3M

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

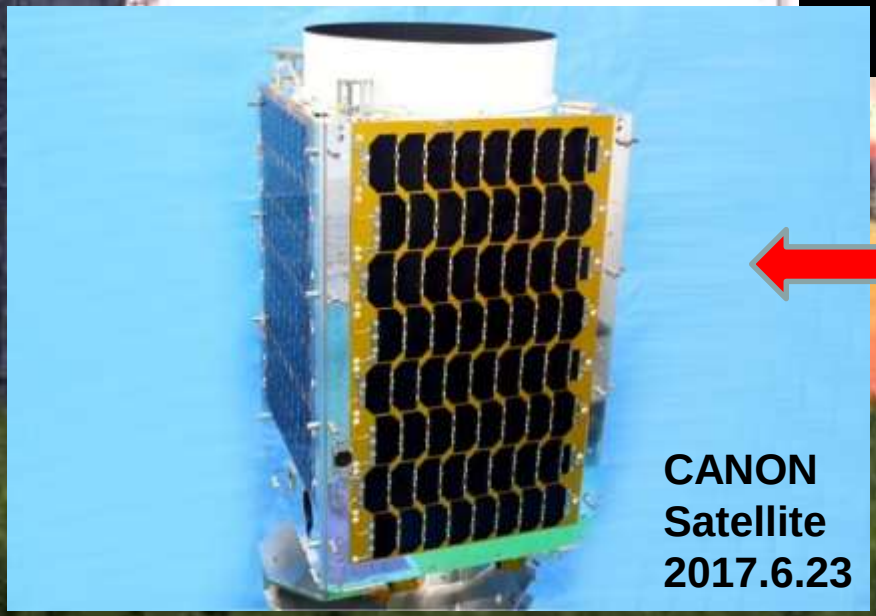
- ***Practical Training of Whole Cycle of Space Project***
  - Mission conceptualization, satellite design, fabrication, ground test, modification, launch and operation
  - Know what is important and what is not.
- ***Importance for Engineering Education***
  - Synthesis (not Analysis) of an really working 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
- ***Also contributions to other technology areas !***

Launch of the World First CubeSat (XI-IV, etc) by “ROCKOT”

2003/06/30 18:15:26 (Ru

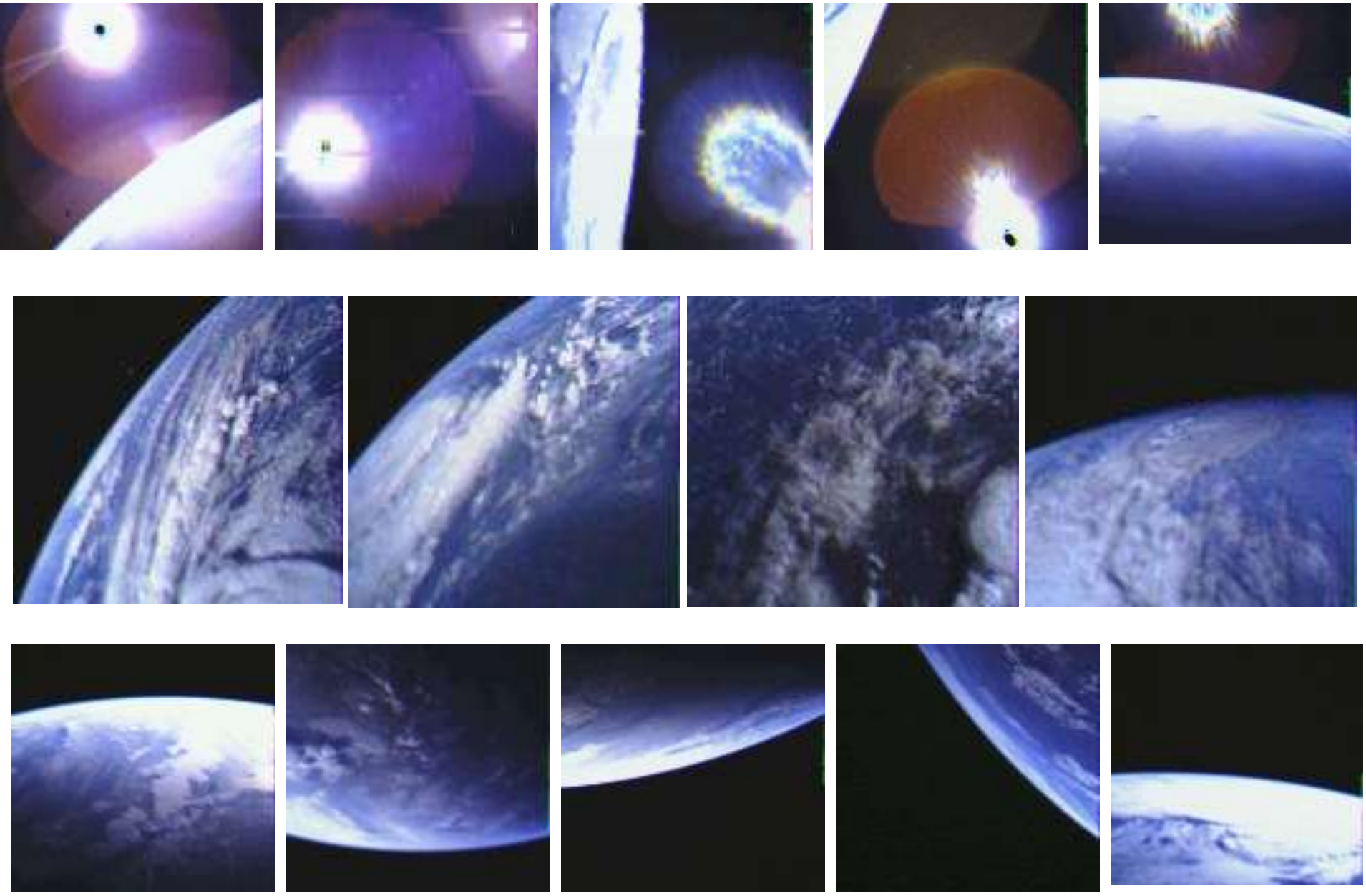
Contributions to human resource training is more than expected !

Hayabusa-2



CANON Satellite 2017.6.23

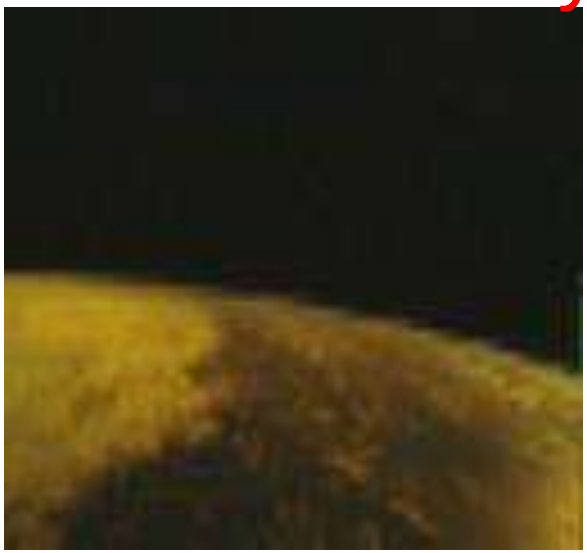
700+ pictures downlinked for 14+ years

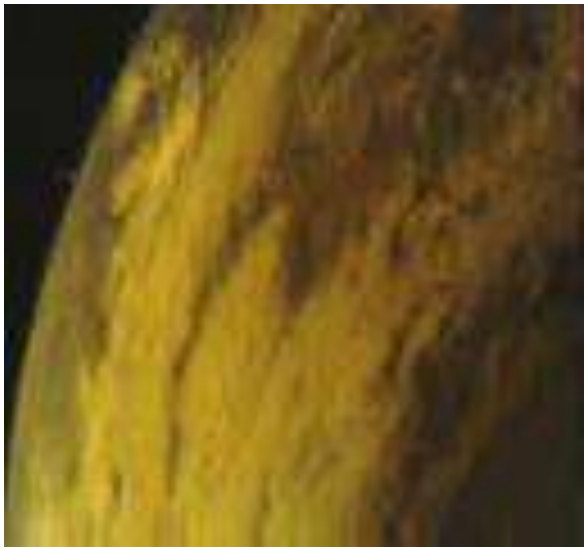


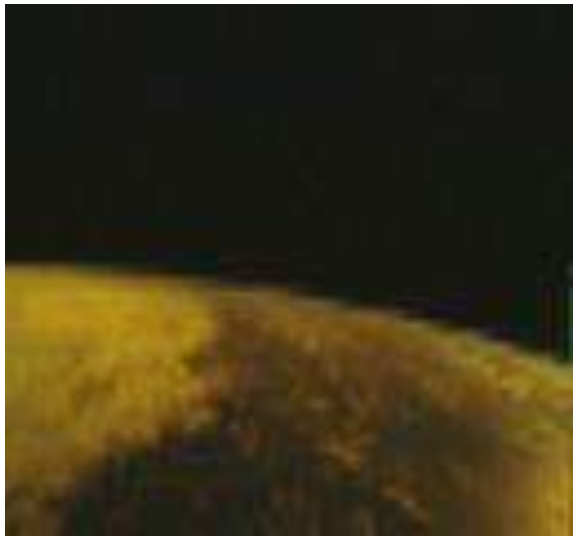
XI-IV is still perfectly working after 14+ years in orbit

Recently Downlinked Photos

Sepia color !
Get older ?







Key strategy to be world first CubeSat

- No components on web-site for CubeSat
  - Everything should be internally-made
- No ground test facilities in our university
- We only have little money ($50,000)
- Key strategies employed in 1st CubeSat
  - Find out and pursue what we can do within your limited resources
  - Find outside supporters (technical, part donation)
  - Make it as simple as possible (start from very simple CubeSat)
  - Implement survivability as much as possible

UNISEC supported student projects !!

(UNIversity Space Engineering Consortium)

- Founded in 2002, became NPO in 2003
- 72 laboratories from 50 universities
- 892 students, 259 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

University Satellites in Japan

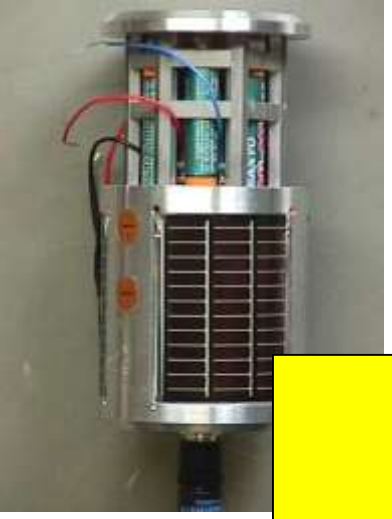
44 university satellites launched in 2003-2016

From CanSat to CubeSat, Nano/micro-Satellite

Almost all the universities have CanSat experiences !

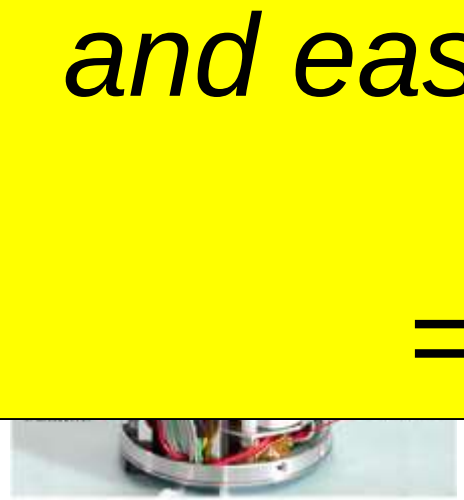
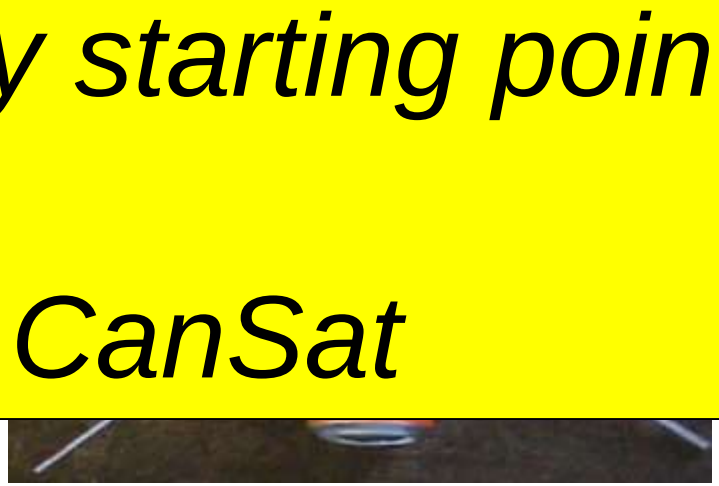
What realized UNISEC Achievements ?

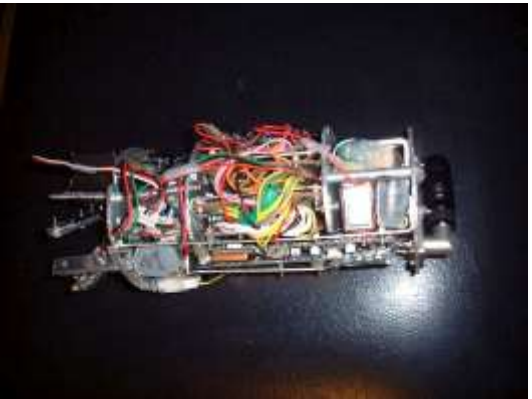
- UNISEC provided university students with platform = opportunities to observe and exchange;
  What other universities achieved and how, leading to
  - strong motivation (we can do something similar!!)
  - hints of achieving something (rocket, satellite, CanSat, real satellites, ---)
  - competitive (“rival”) feeling (if they can do it, we can do it better !!)
- As one community, we have been negotiating with government and companies asking for their support in many aspects (technology, finance, facility, legal issues, launch opportunity, etc.)




Simple, low cost
and easy starting point

= CanSat



ARLISS (A Rocket Launch for International Student Satellites)
- Annual suborbital launch experiment -

- ARLISS 1999：Sept. 11 (Japan:2, USA:2)
  - Univ.of Tokyo, Titech, Arizona State, etc.
- ARLISS 2000: July 28-29 (Japan:4, USA:3)
- ARLISS 2001: August 24-25 (Japan:5, USA:2)
- ARLISS 2002: August 2-3 (Japan:6, USA:3)
- ARLISS 2003: Sept.26-27 (Japan:6, USA:3)
- ARLISS 2004: Sept.24-25 (Japan:6, USA:3)
- ARLISS 2005: Sept.21-23 (Japan:7, USA:3)
- ARLISS 2006 Sept.20-22 (Japan:8 USA:3 Europe:1)
- ARLISS 2007 Sept.12-15 (Japan:10 USA:3 Korea:1)
- ARLISS 2008 Sept.15-20: 10th Memorial ARLISS !

- ARLISS 2016 18th （Japan:12, USA:2, Korea, Egypt)
- ARLISS 2017 19th Sept.13-17 (Japan:13 USA:2 Kore
- ARLISS 2018 20th Memorial !!

CLTP (CanSat education) History & Participants

1 month course "CanSat Leaders Training Program"

64 participants
from 32 countries

CLTP1 (Wakayama Univ. in Feb-March, 2011)
12 from 10 countries, namely Algeria, Australia, Egypt, Guatemala, Mexico, Nigeria, Peru, Sri Lanka, Turkey (3), Vietnam.

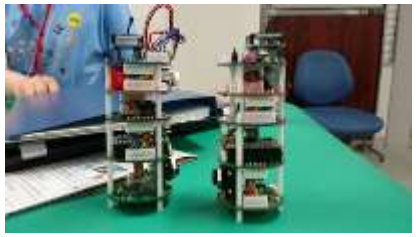
CLTP2 (Nihon Univ. in Nov-Dec, 2011)
10 from 10 countries, namely Indonesia, Malaysia, Nigeria, Vietnam, Ghana, Peru, Singapore, Mongolia, Thailand, Turkey.

CLTP3 (Tokyo Metropolitan Univ. in July-August, 2012)
10 from 9 countries, namely Egypt (2), Nigeria, Namibia, Turkey, Lithuania, Mongolia, Israel, Philippines, Brazil.

CLTP4 (Keio Univ. in July-August, 2013)
9 from 6 countries, namely Mexico(4), Angola, Mongolia, Philippines, Bangladesh, Japan.

CLTP5 (Hokkaido Univ. in Sept 8-19, 2014)
7 from 5 countries, namely Korea (2), Peru, Mongolia, Mexico (2), Egypt.

CLTP6 (Hokkaido Univ. in August 24-Sept 3, 2015)
8 from 8 countries, namely Bangladesh, Egypt, Mexico, New Zealand, Angola, Turkey, Tunisia, Austria



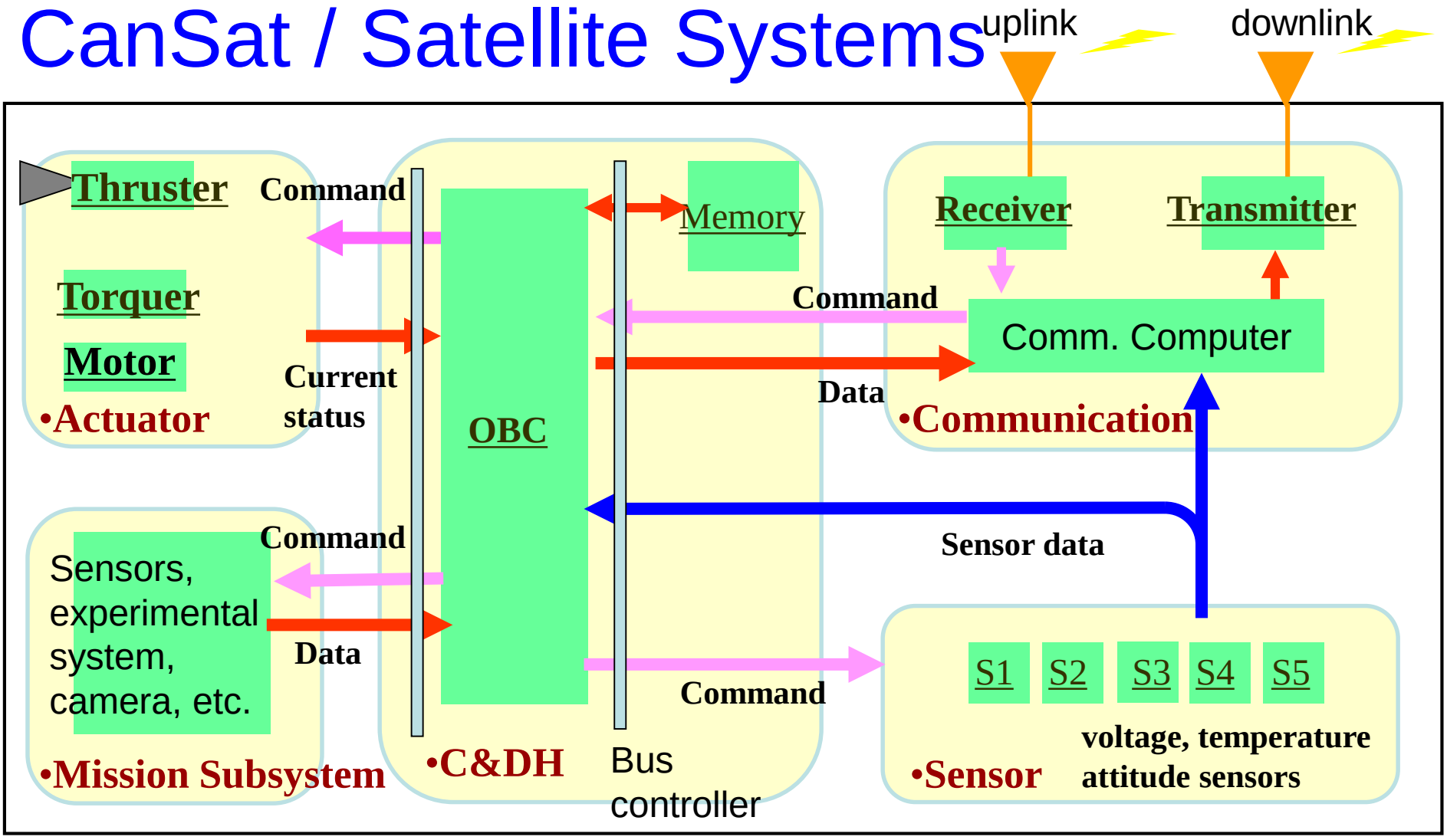
CLTP7 (Hokkaido Univ. in Sept 21-Oct 1, 2016)
8 from 7 countries, namely Egypt, Peru, Mongolia, Nepal, Myanmar, Serbia, Dominica Republic

Learn from Failures

Parachute part and body was separated by the shock of the deployment of the parachute

Failure should be experienced many times and fully analyzed <u>while project size is small</u> !

CanSat / Satellite Systems

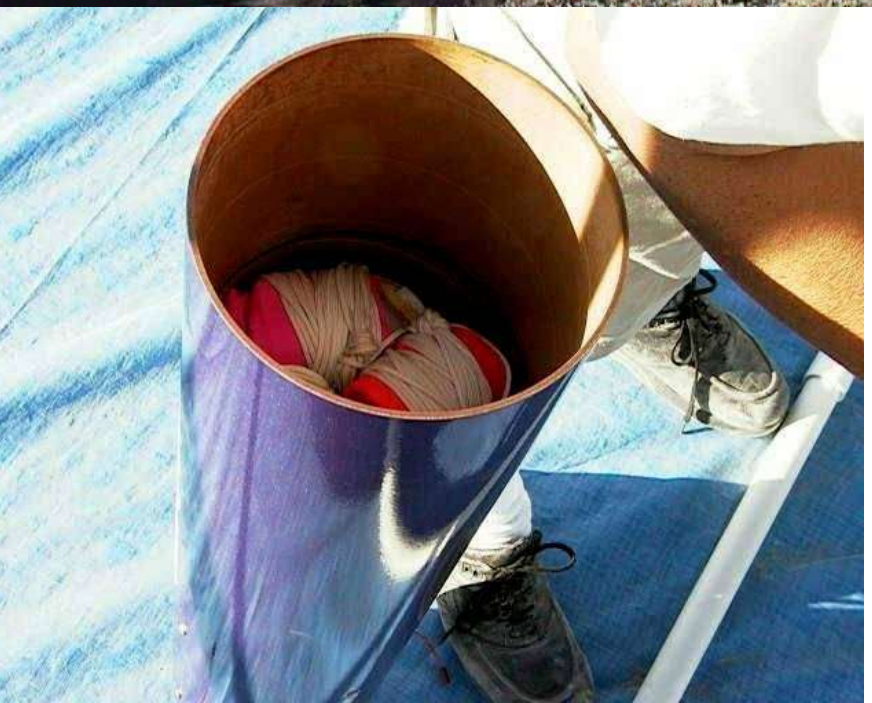


Power System

Battery

Structure and Mechanism System

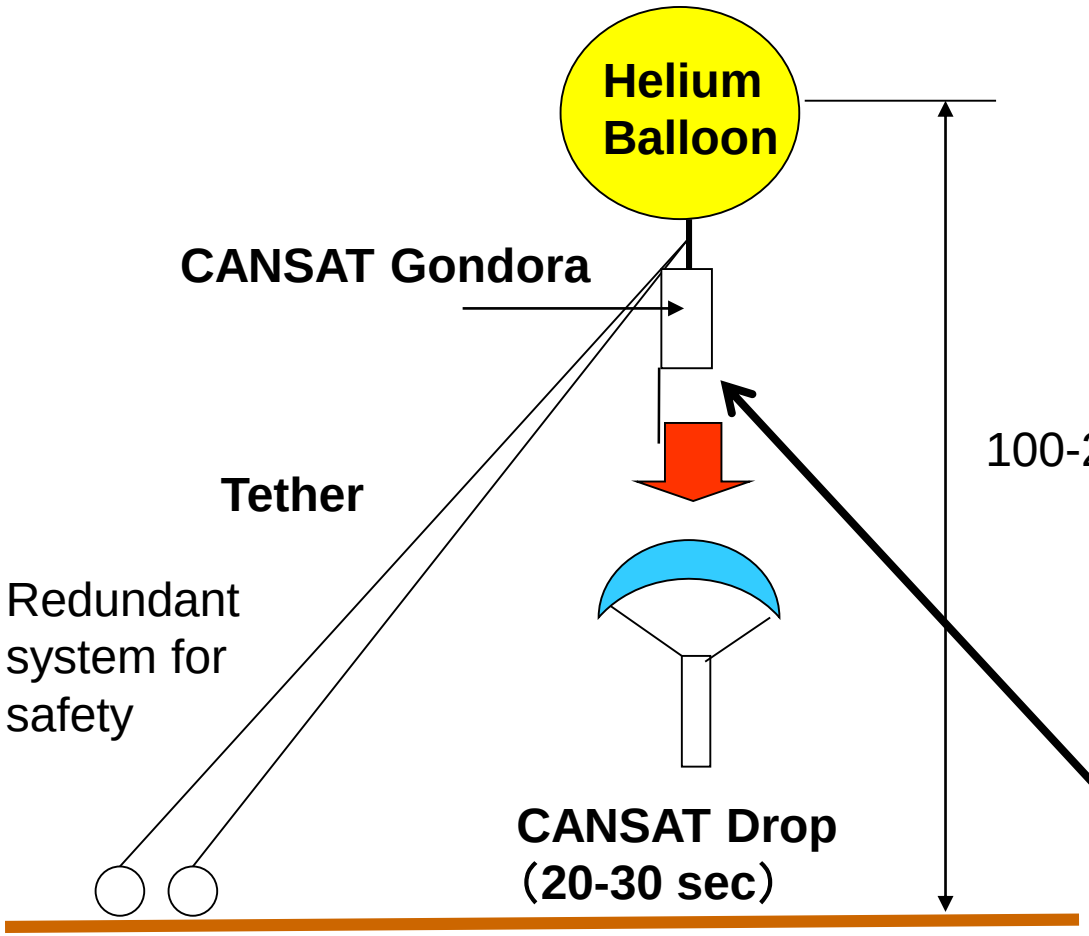
Loading to inside of rocket nose-corn



1st ARLISS Sep.1999

CanSat Deployment using Helium Balloon

Drone or UAV are also used recently



RF signal to open the door

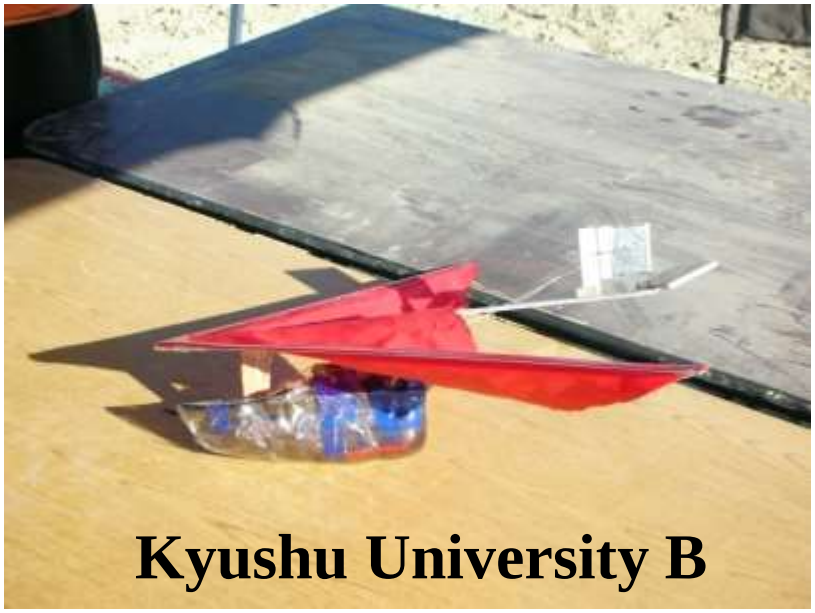
Radio controller (“propo”)

Simple criteria, Competition makes motivation

Fly-backers


Kyushu Tech KINGS


Titech Str. Dynamic Lab


Kyushu University B


Keio University

2017 Champion

University of Tokyo’s rover achieved

0m

to the target

“Non-maintainable System”

- A satellite, even a CanSat cannot be contacted until the end of its mission once it is loaded on a rocket or balloon

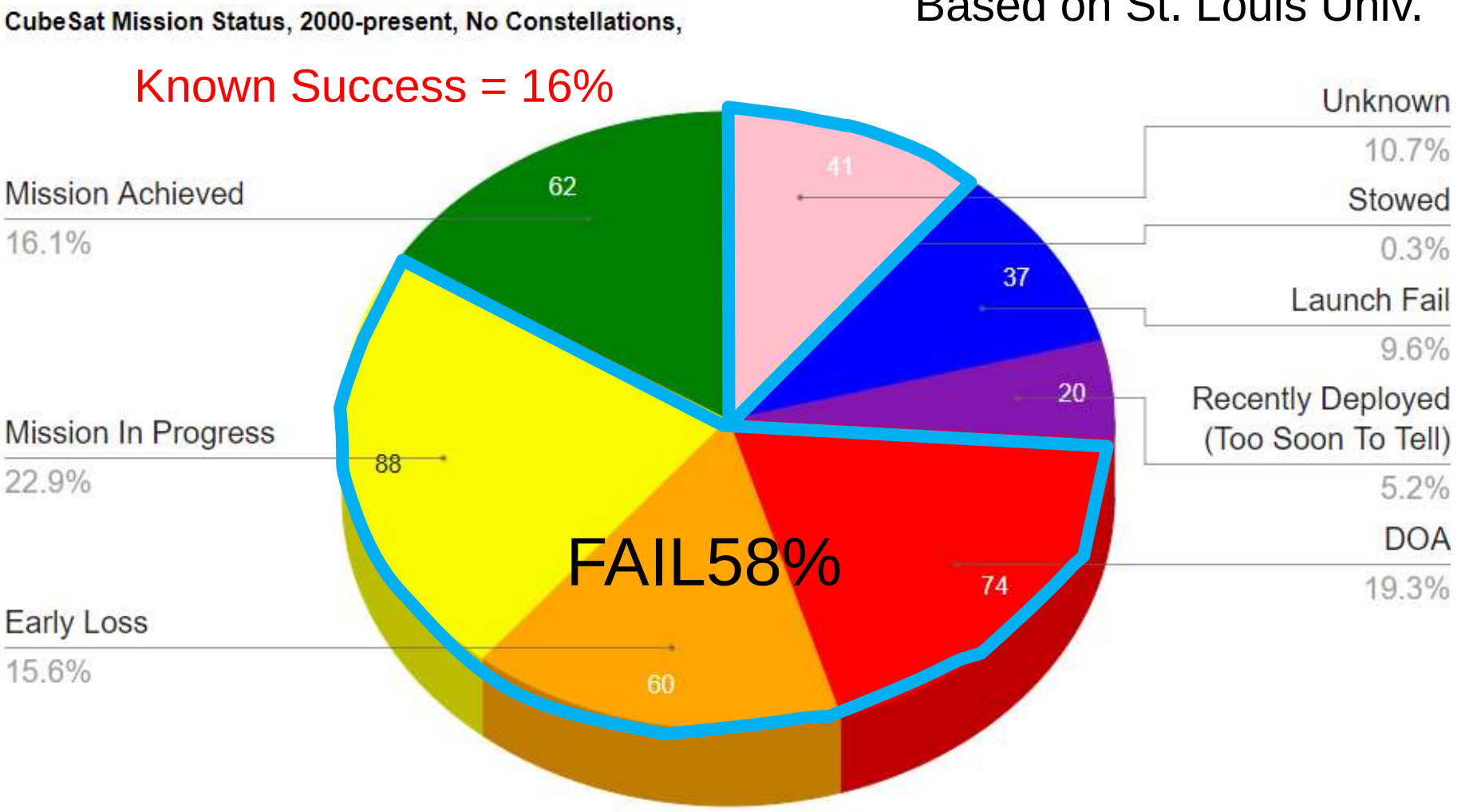
“non-maintainable system”

- Sometimes it should survive in space for more than 10 years without any human interactions, so

- Imagine all the possible events and anomalies which may happen on Satellite or CanSat and prepare countermeasures for them
- Try as many ground test as possible in various settings to ensure normal operations of CanSat

To reduce the current CubeSat failure rate(58%)

Based on St. Louis Univ.



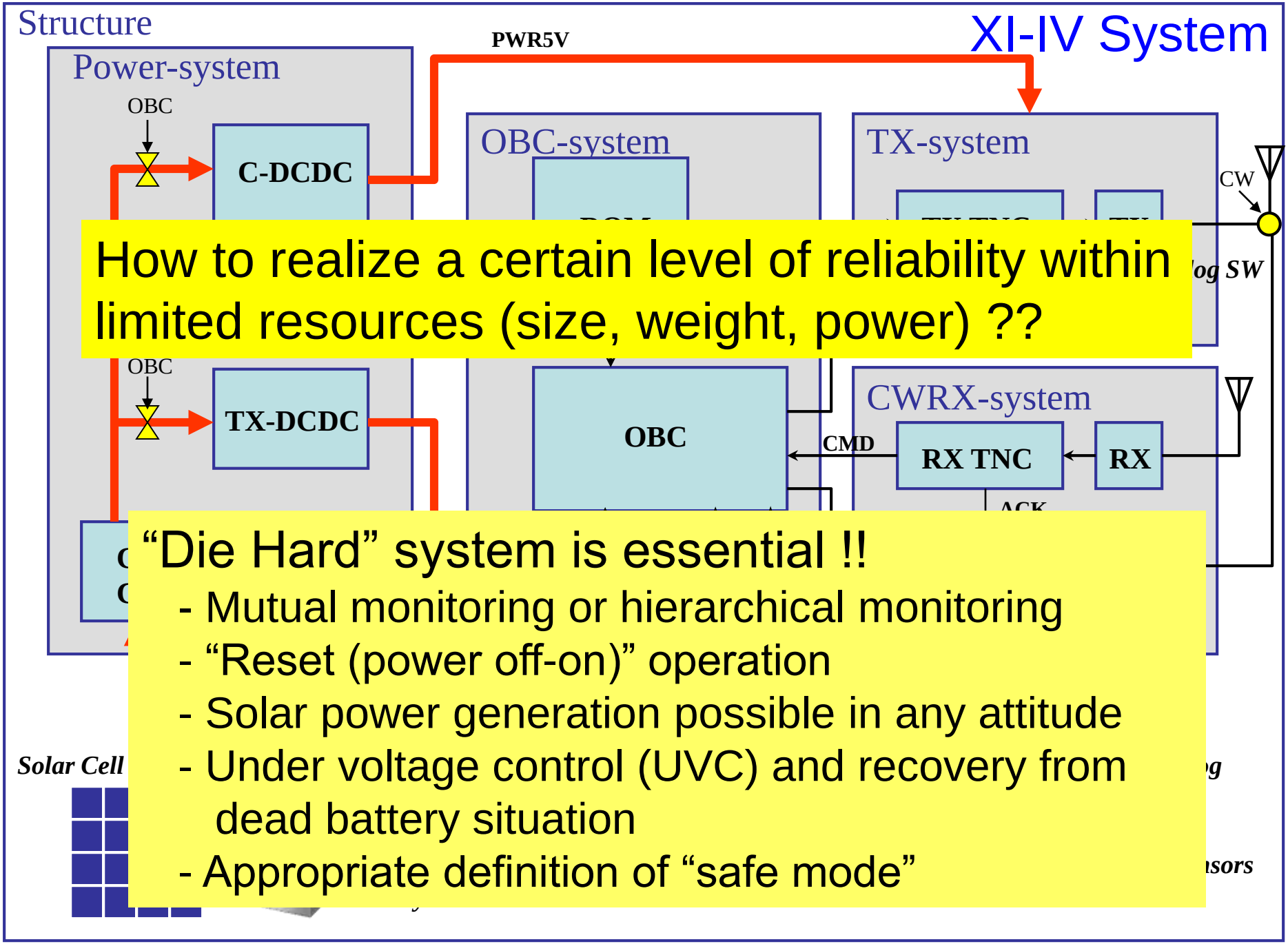
https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database

Space Environment

■ Vacuum	Vaporization, cold welding, friction, electric discharge, change of material, heat spot….
■Radiation	Electronics parts malfunction and breakdown, Degradation of solar cells and materials…..
■Thermal	Large temperature differences/cycles, heat shock, heat spot…..
■Launch	Vibration, shock, acceleration, sound vibration…..
■Distance	No maintenance possible, long range communication, tracking required…..

Do required tests: Standardization of Tests for Lean Satellite

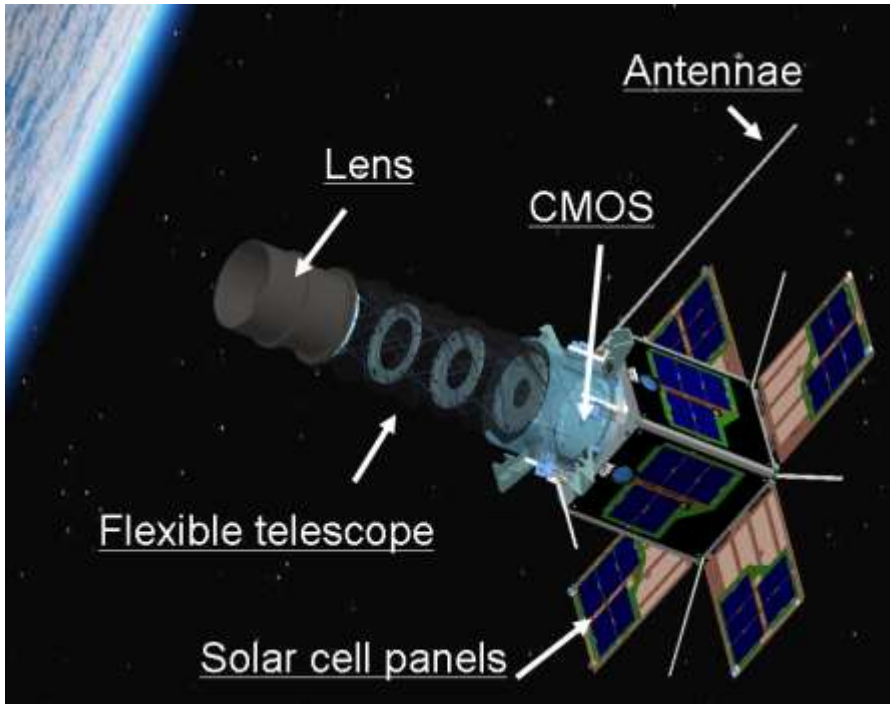
One month "Burn-in" after completion of your satellite

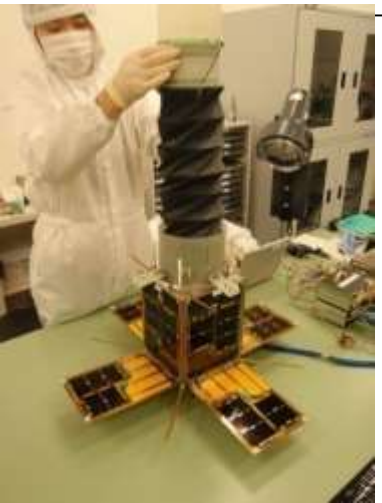

Structure
XI-IV System
PWR5V
Power-system
OBC
C-DCDC
OBC-system
TX-system
CW
How to realize a certain level of reliability within limited resources (size, weight, power) ??
OBC
TX-DCDC
OBC
CWRX-system
CMD
RX TNC
RX
“Die Hard” system is essential !!
- Mutual monitoring or hierarchical monitoring
- “Reset (power off-on)” operation
- Solar power generation possible in any attitude
- Under voltage control (UVC) and recovery from dead battery situation
- Appropriate definition of “safe mode”
Solar Cell

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

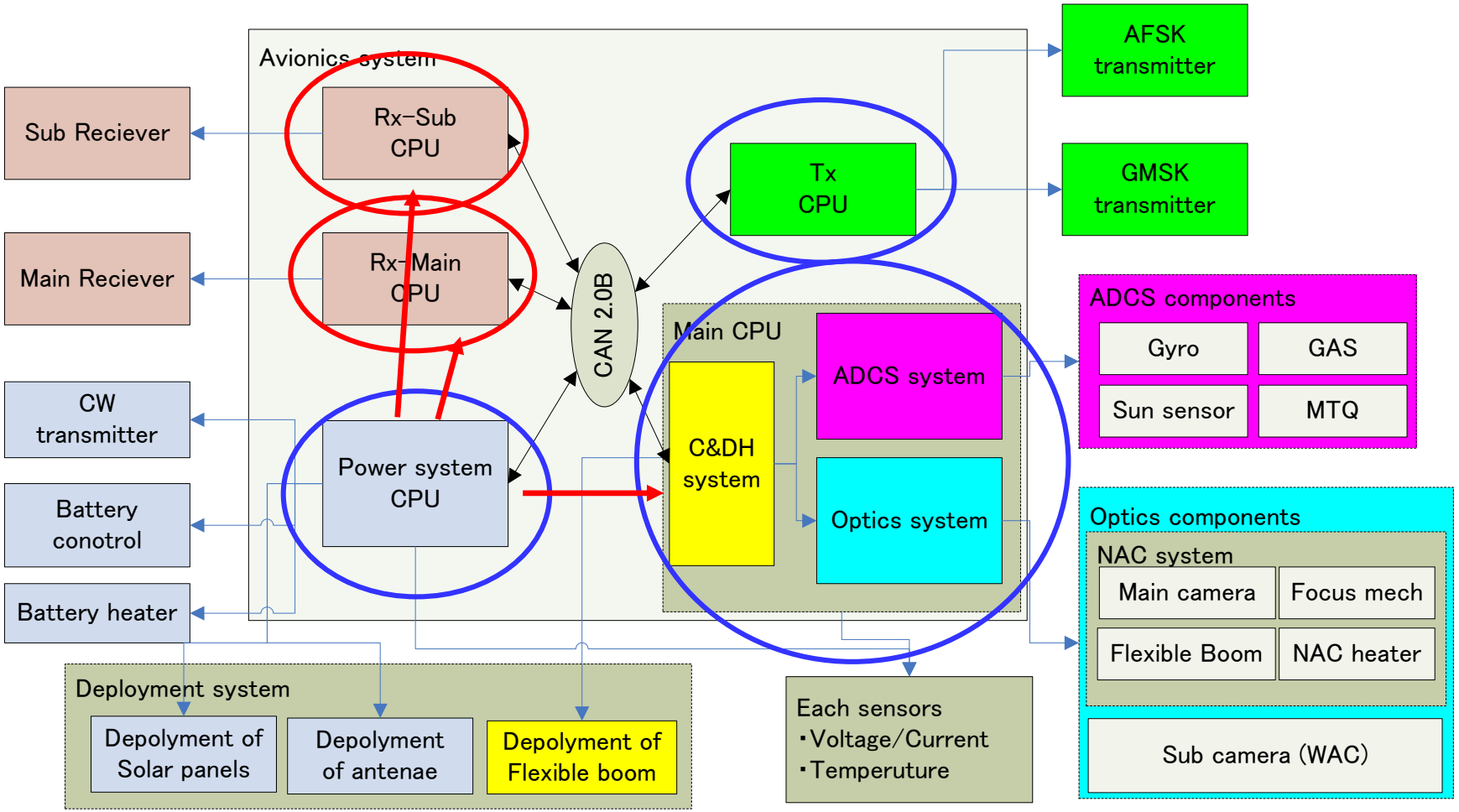
Mexico Seashore

US Desert

Kita-Kyushu (Japan)

Wide Angle Camera

PRISM System Diagram



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

Step up to practical applications

2010～

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

Target: 50kg class satellite to be developed within $3M and 2 years

Size:50x50x80cm 60kg Downlink: 10Mbps Power: max 100W average 50W

Attitude Control Capability:

- Stability	0.08 deg/s (Roll, Pitch)	0.8 deg/s (Yaw)
- Pointing accuracy	0.2 deg	2 deg
- Determination accuracy	0.0048 deg	0.048 deg


Sri Lanka
(LCAM 240m GSD)

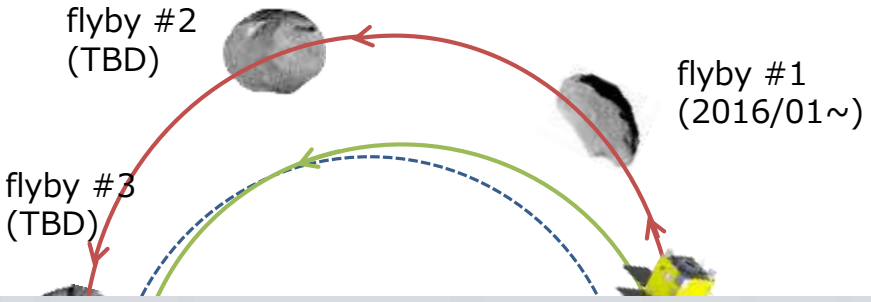

Chiba
（6m GSD)


Dubai (6.7mGSD)
©AXELSPACE

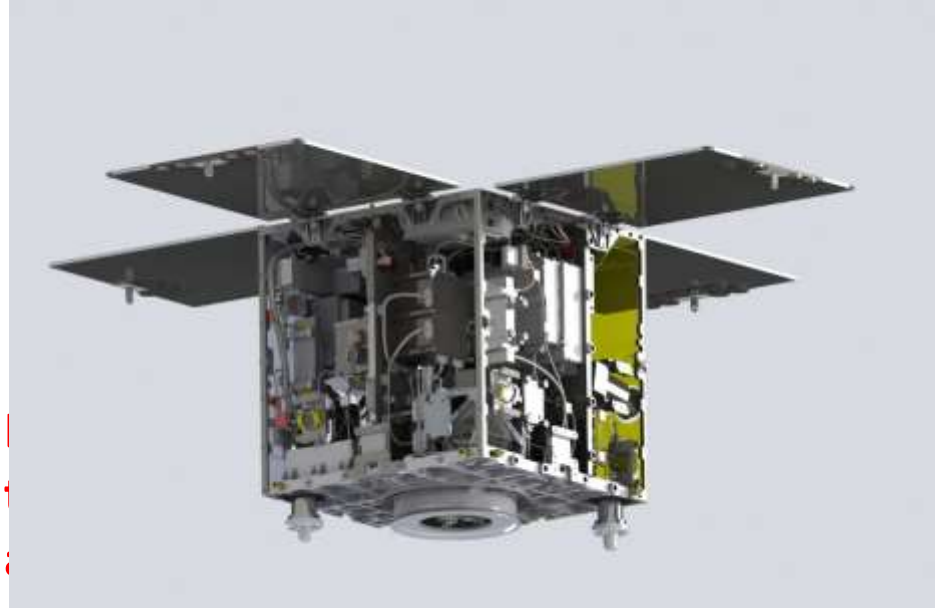
50kg-class deep space probe "PROCYON"

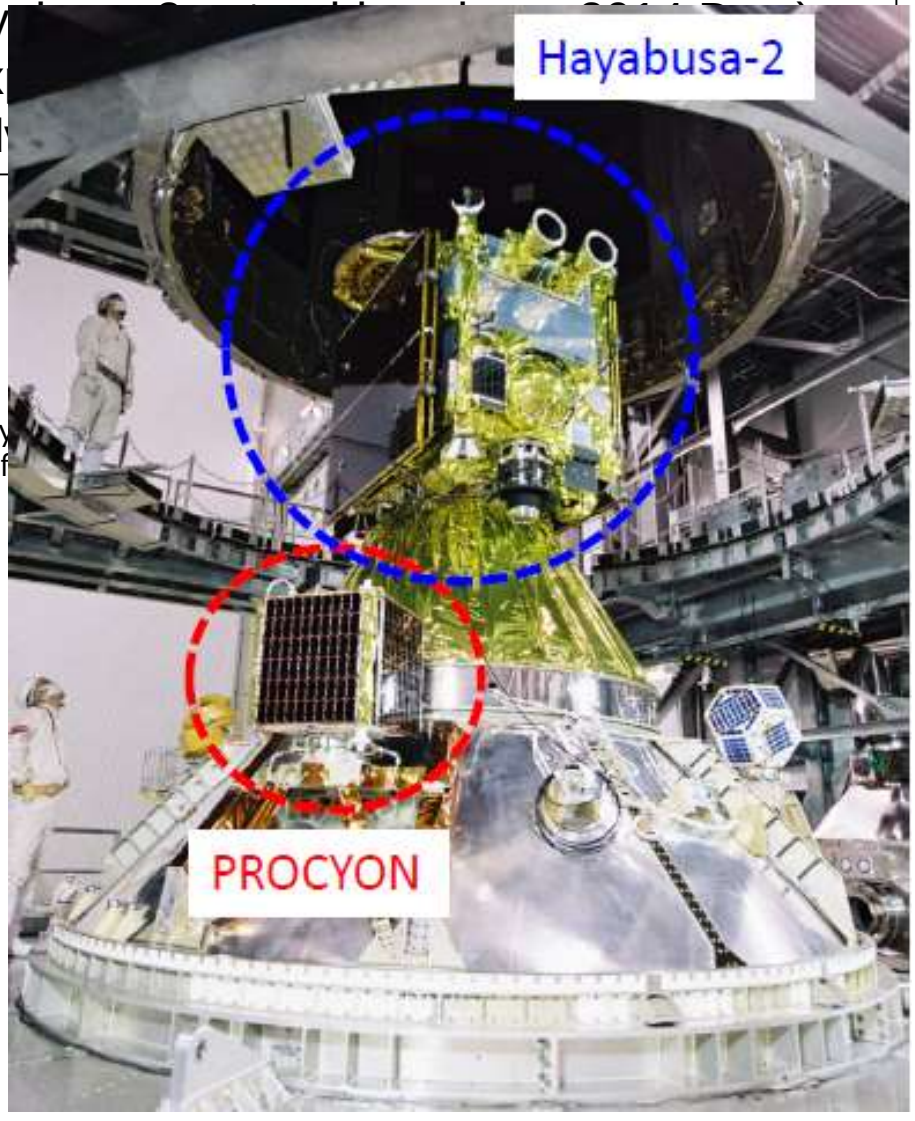
(PROCYON: PRoximate Object Close flYby with Optical Navigation)

Developer: **Univ. of Tokyo and JAXA** (Japan Aerospace Exploration Agency)
Launch: H2A rocket (together with Hay
Mission: Demo. of 50kg deep space ex
Asteroid flyby observation (ad



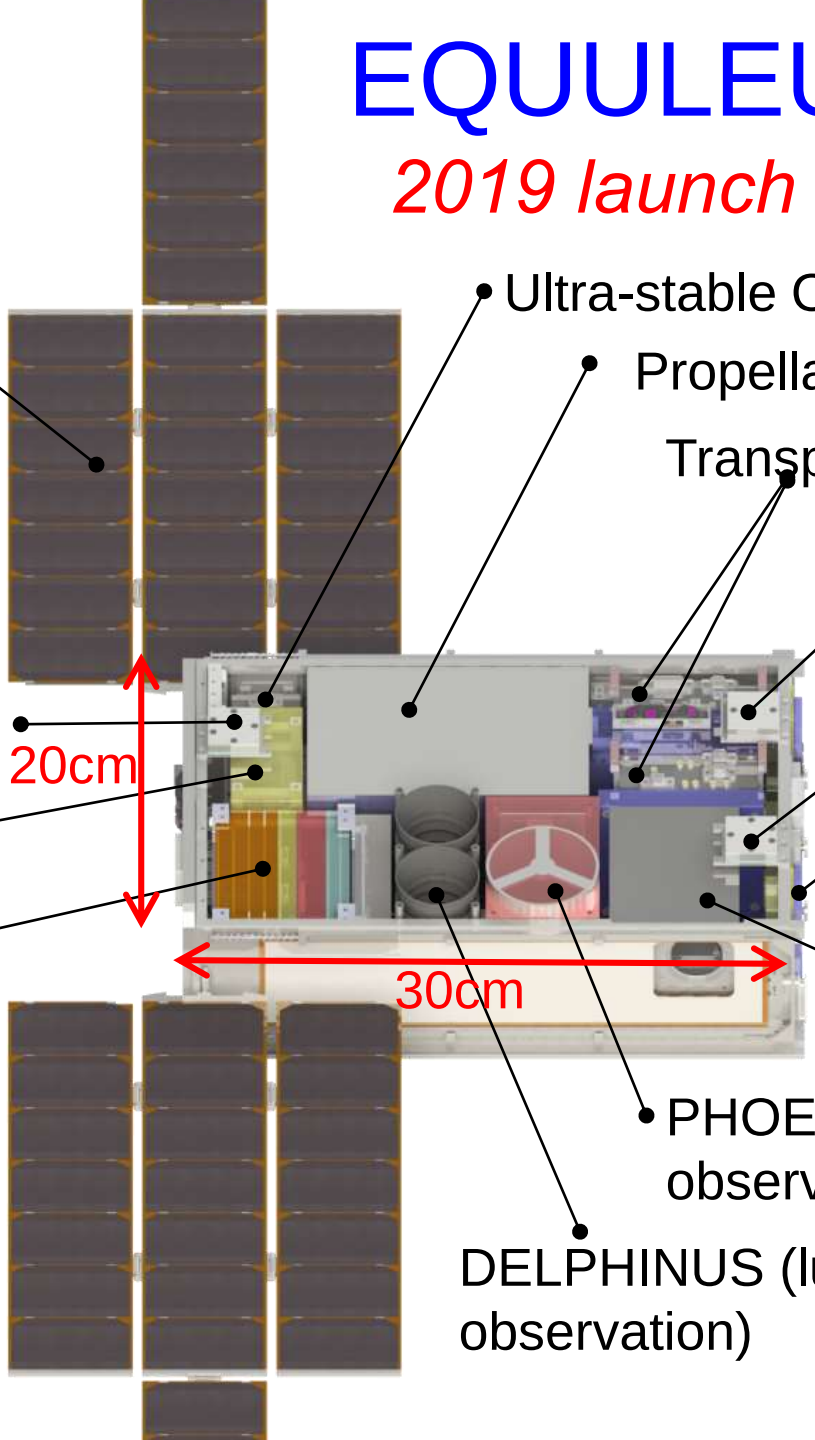
Flyby
> a f





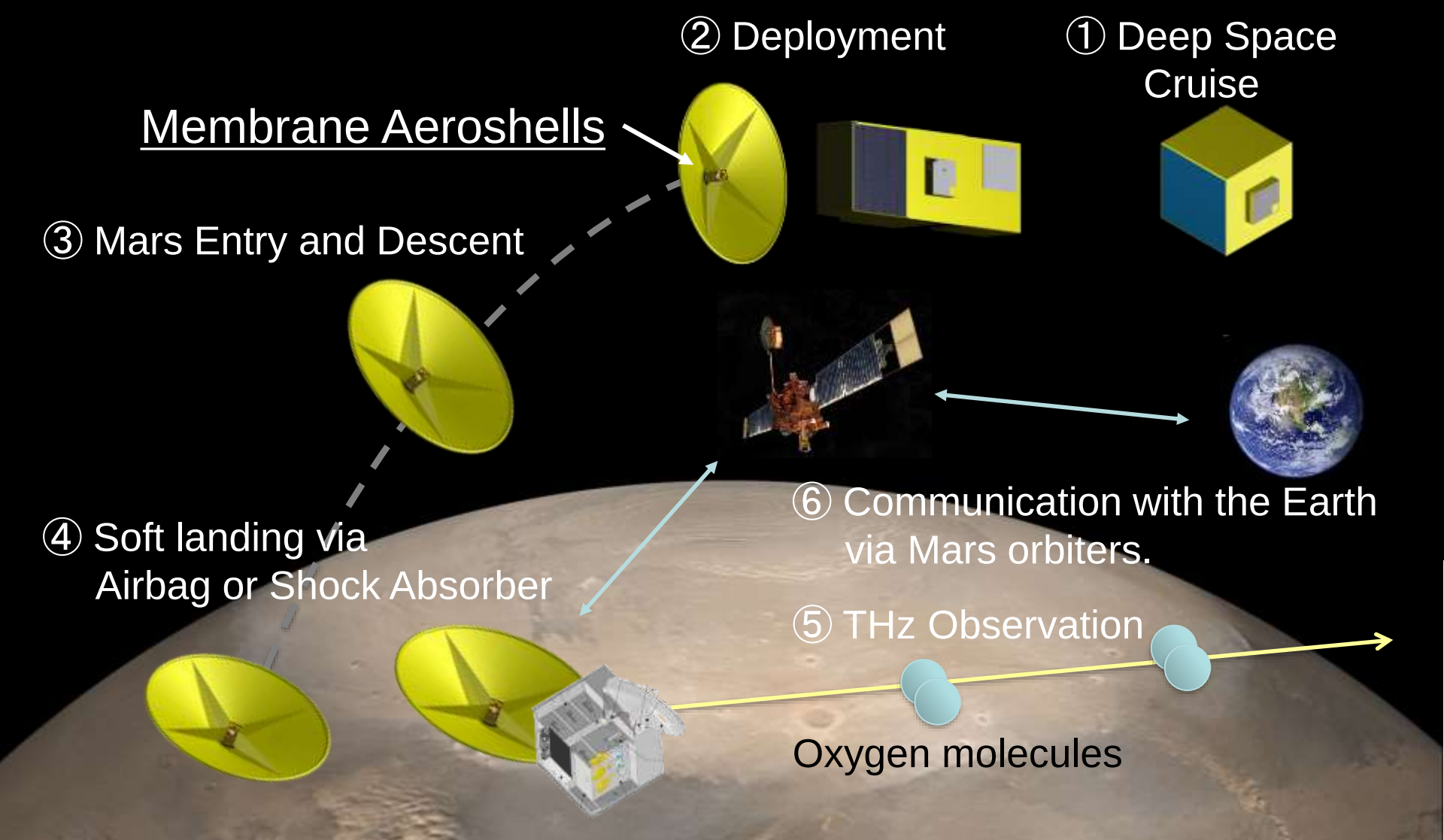
EQUULEUS to EML2

2019 launch by NASA' s SLS-1



Mars Micro-Lander Project Just Started

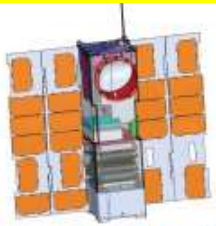
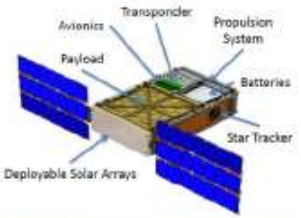
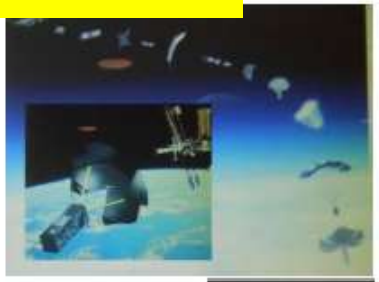
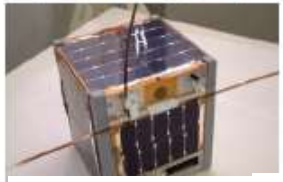
NICT, University of Tokyo, et. al. started preliminary design.
Size: 70-100kg Planned launch date in July 2022



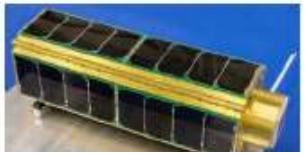
Growing trend of < 50kg satellites

Innovative utilizations of Micro/nano/pico satellites







Education | Remote sensing | Telescope | Weather | Bio-engineering | Re-entry

OPUSAT(1U:1kg)
XI-IV(1U:1kg)

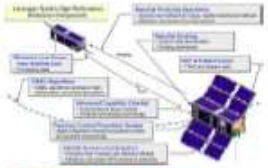
AeroCube(1.5U:2kg)
Dove,Flock(3U:4kg)

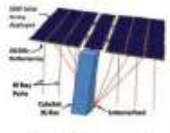
AAReST

MiRaTA(3U)
MicroMAS(3U)

BioSentinel計画案(6U)
SPORESAT(3U:5.5kg)

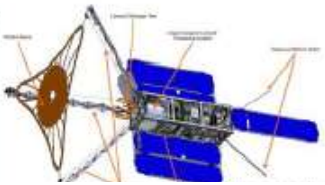
再突入回収(3U)
Sunjammer

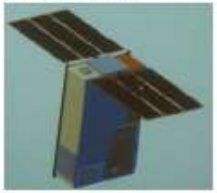


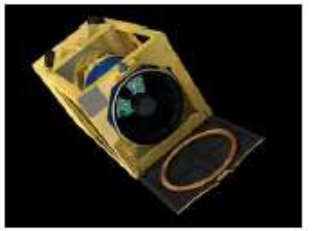












Rendezvous/ docking | Communication | Space Science | Atmosphere | Exploration | High Resolution.

INSPIRE(3U)

高速通信・ISARA(3U)
低速通信・AISSAT-1(6kg)

RACE(3U)
FS-7(3U)

(可視・近赤外)
NEMO-AM(15kg)

LWaDi(6U)
CAT(3U)

SCOUT(50kg)
Skysat(120kg)

Primarily by university/venture companies, but governmental projects are also appearing, which begin to replace mid-large sized satellites.

“Game Change” by “Lean” Satellites

- Very low cost (>200M$ → <5M$)
  - Leads to new missions, business, space sciences…
- Make the most of these merits of micro/nano/pico-satellites.
- Do not develop them “like big satellites.”
- Focus on dedicated one or two missions and find appropriate mission level !!
- Simple and transparent satellite system
  - Easy to design, operate and do trouble shooting
  - Development members can see the total system

Nano-JASMINE

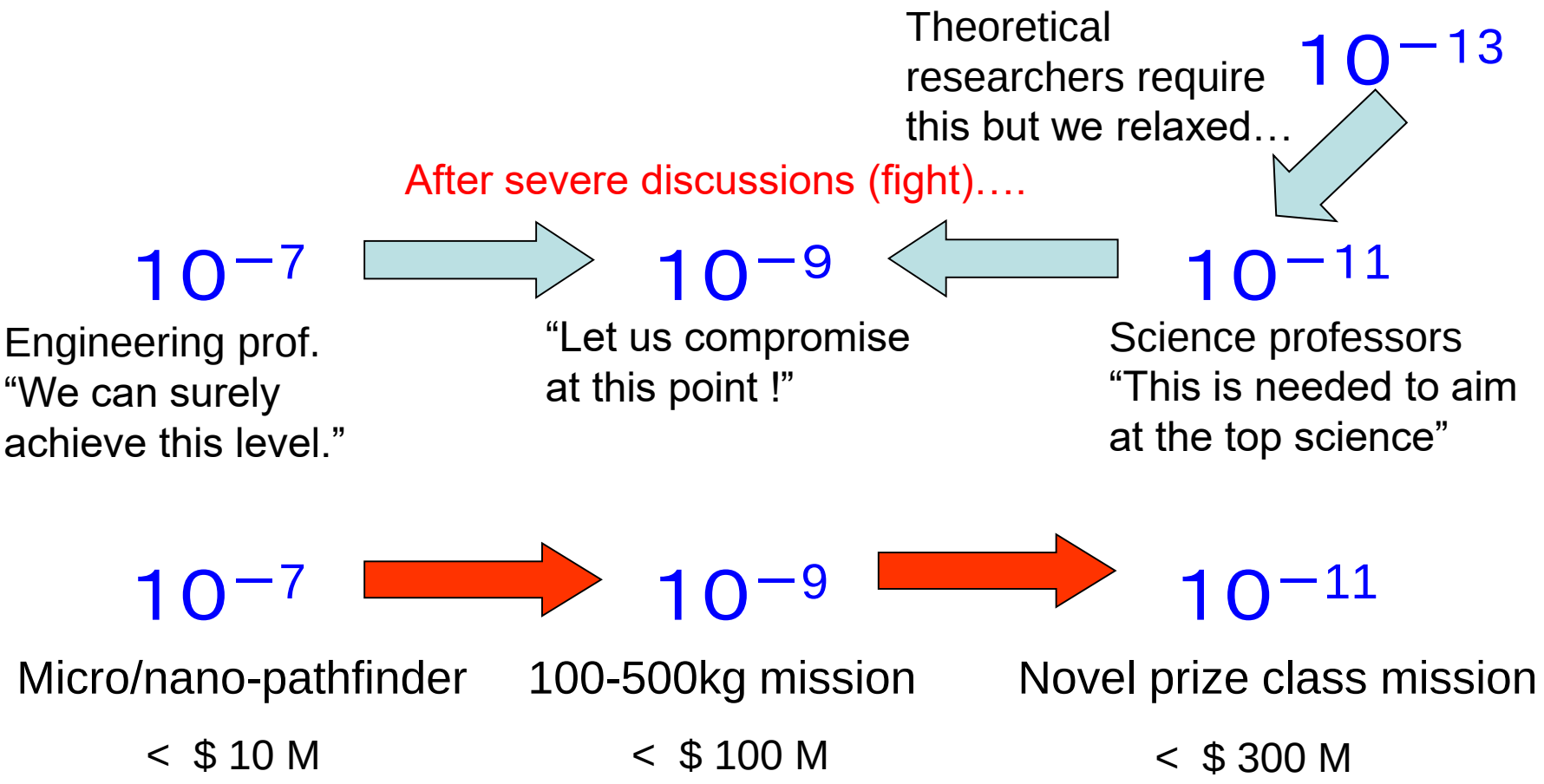
Mission: Astrometry (Getting precise 3D map of stars and their movements)
Developer: University of Tokyo, National Astronomical Observatory of Japan, Shinshu University, Kyoto University
Launch: TBD

Size	50 [cm-cubic]
Weight	37 [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

Collaborating with “Users” (scientists)



Quickly start with “not perfect” but “good enough” (“Hodoyoshi”) space science or exploration mission!

Let us start UNISEC-GLOBAL Project !

- CanSat world competition
- Store & Forward network for water quality & water level monitoring or other applications
- Open source software and “Virtual satellite” environment

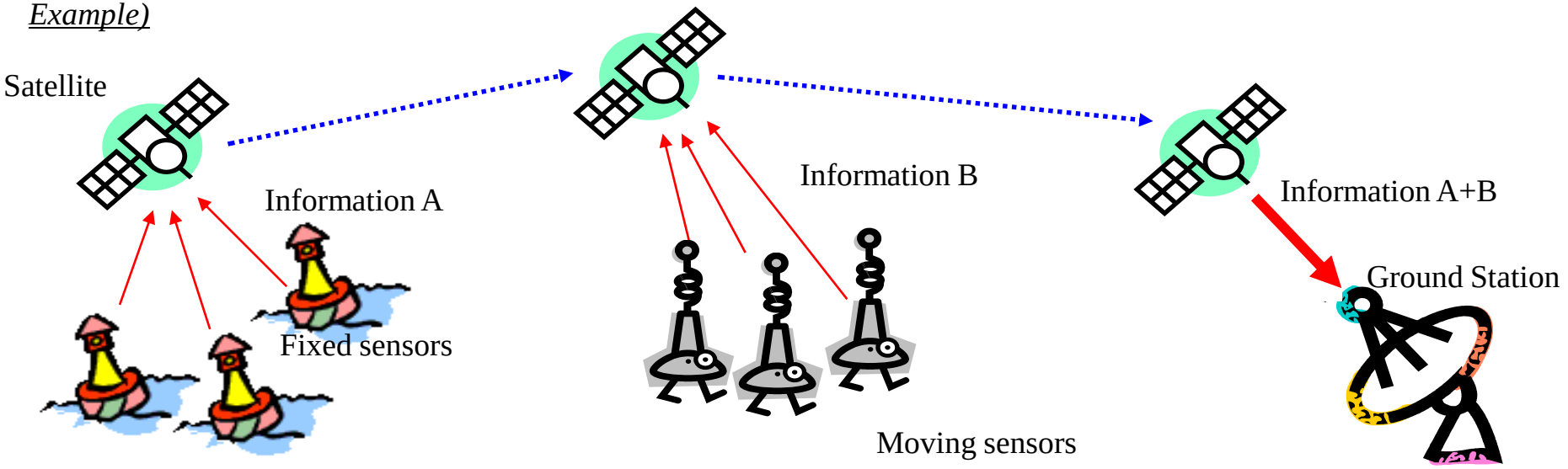
“Store & Forward” gets ground information

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

S&F mission outline

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

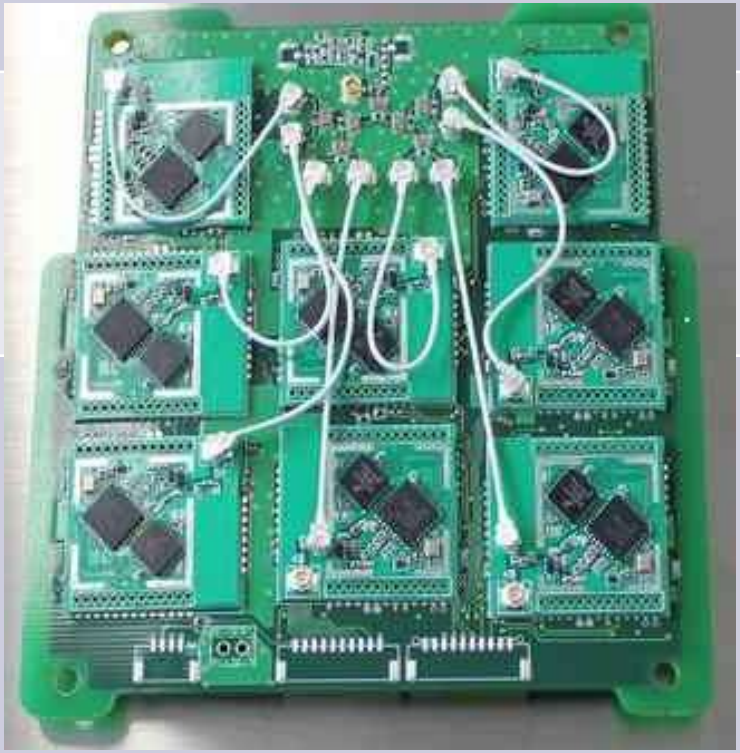
Example)



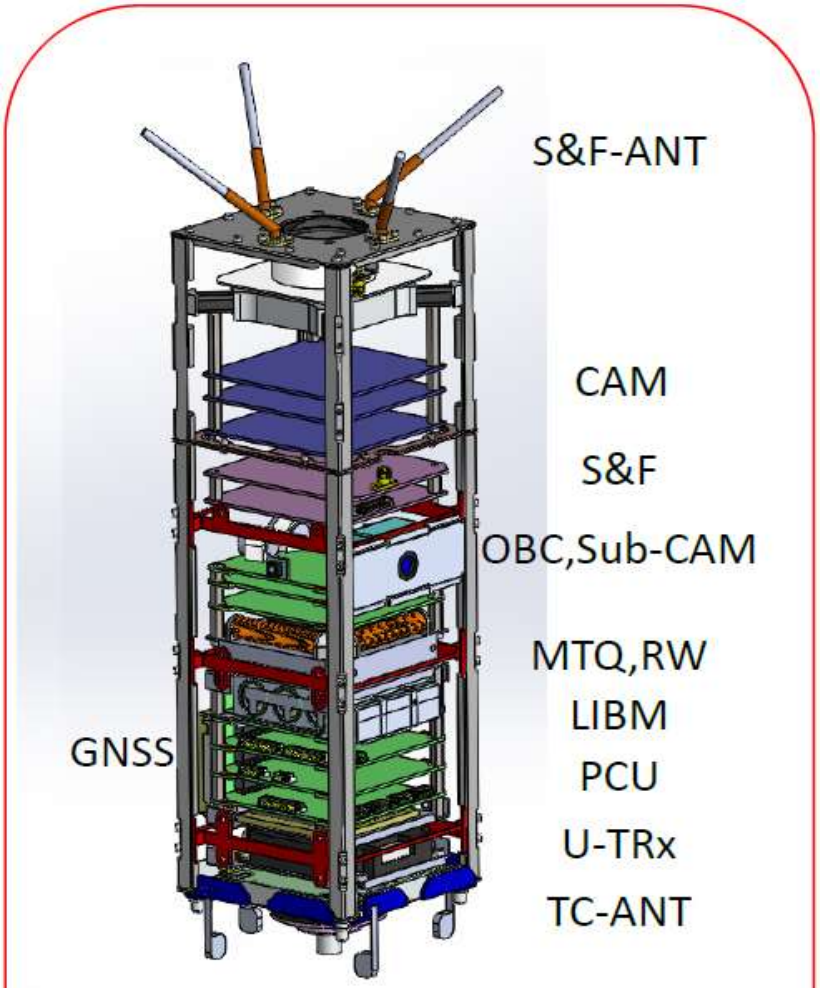
Application areas: disaster prediction, water level monitoring, forest data acquisition…..

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)



3U CubeSat “TriCom-1R”
- Weak signal receiver from ground -



S&F: M2M technology for IoT

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
RF Receiver	20mW RF power from ground	920MHz no license required
Actuators	magnet torquer despun wheel	"MTQ" "RW"
Camera	GSD 314 m VGA @180km	"CAM"
Sub-Camera	GSD 67 m @600km	Five "Sub-CAM"

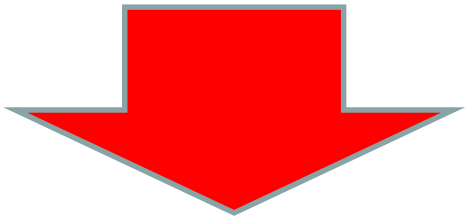
"Modified SS520"

Dedicated rocket for CubeSat by JAXA

Previous launch failed on Jan/2017 but will try it again !

Proposal of S&F Network

- One satellite only provides 4 x 10 min chance of data collection
- If the satellite fails, no backup is provided

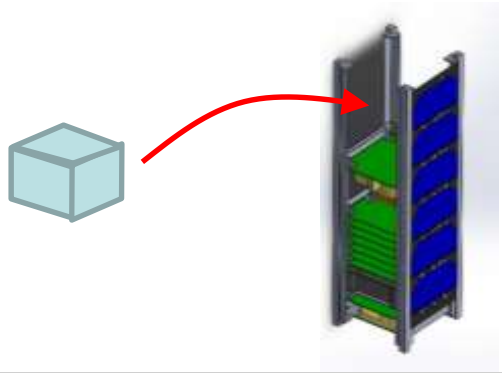


- How about making 2U or 3U by many UNISEC countries so that we can have more time to collect data from ground ?
  - Rule: the country who provides one satellite can use all the satellites for data collection.
  - Standardization of data protocol and communication system should be discussed

Options and Our Supports

- Any Collaboration : Your Idea **X** Our Experience
- All options can include capability building programs

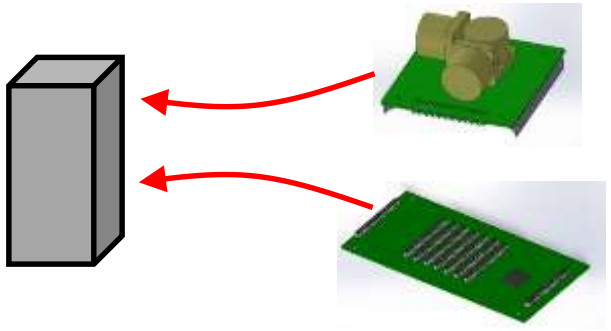
Your Mission × Our 2U/1U S&F BUS



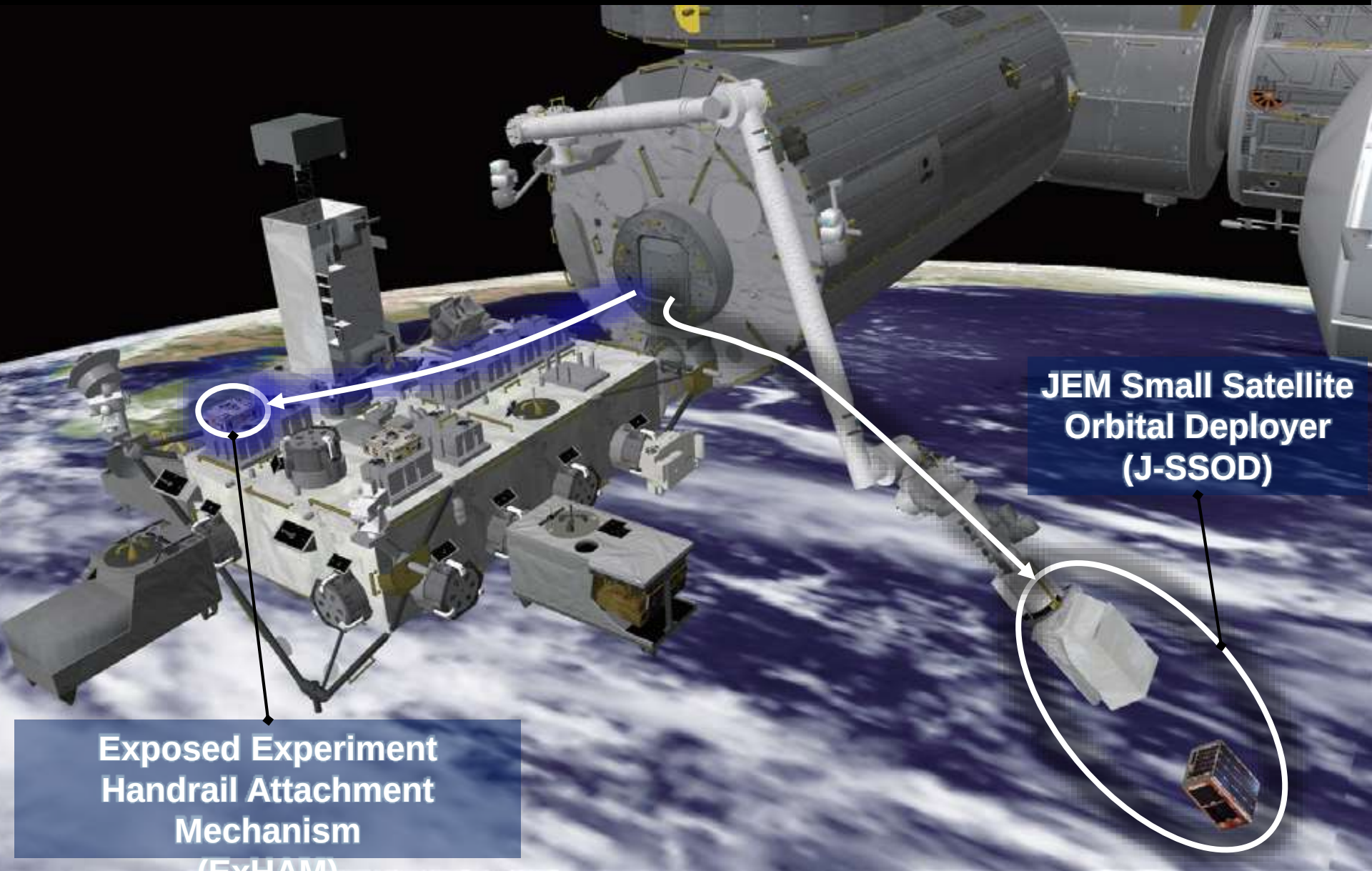
Your Members × Our 3U/2U S&F Cubesat (build Together!)

Your Bus × Our S&F Mission Board

Your Bus × Our Heritage Components



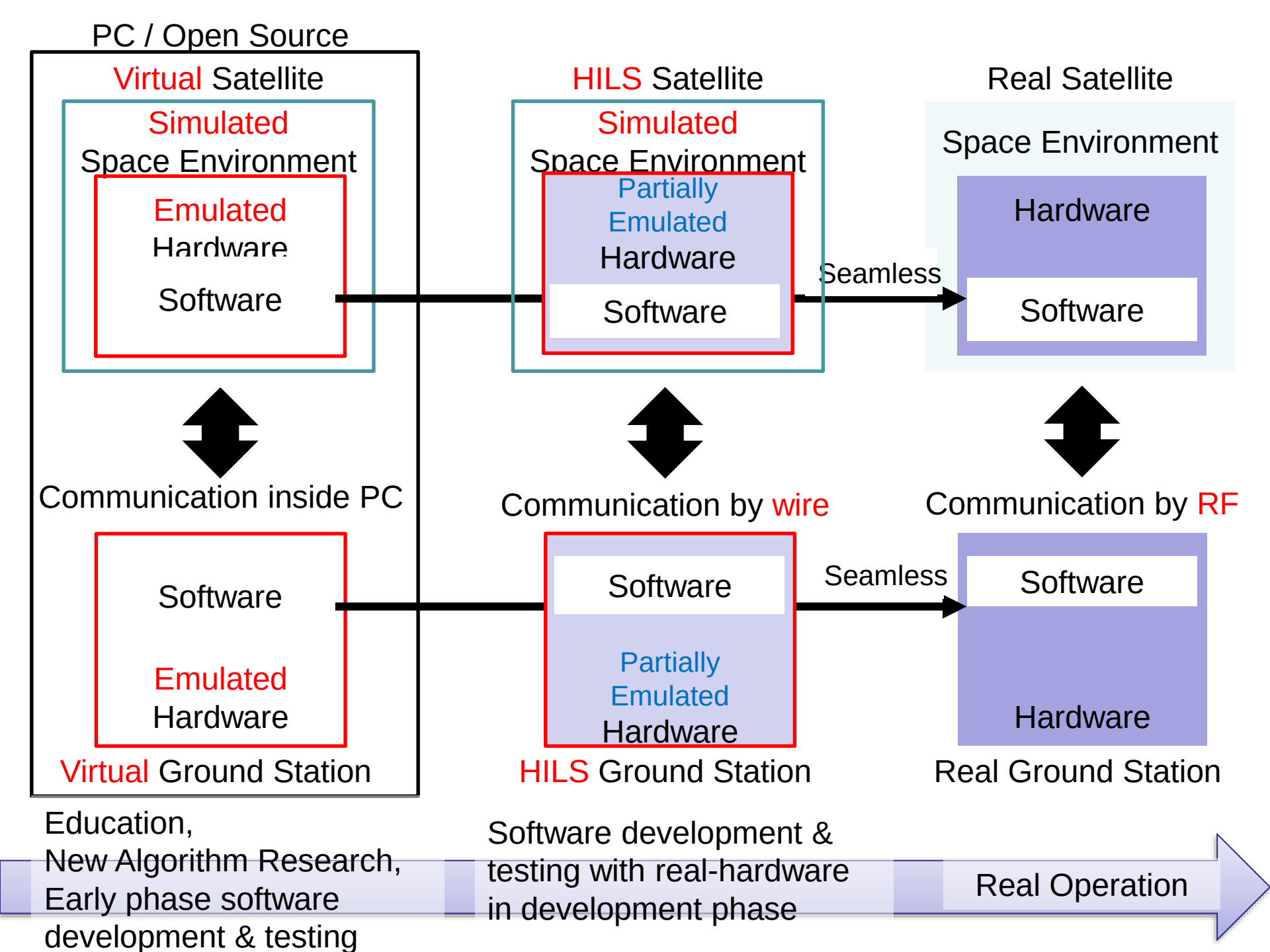
Launch (deployment) from ISS with Kibo Unique Exposed Facility



Open Source Software and "Virtual Satellite" Environment

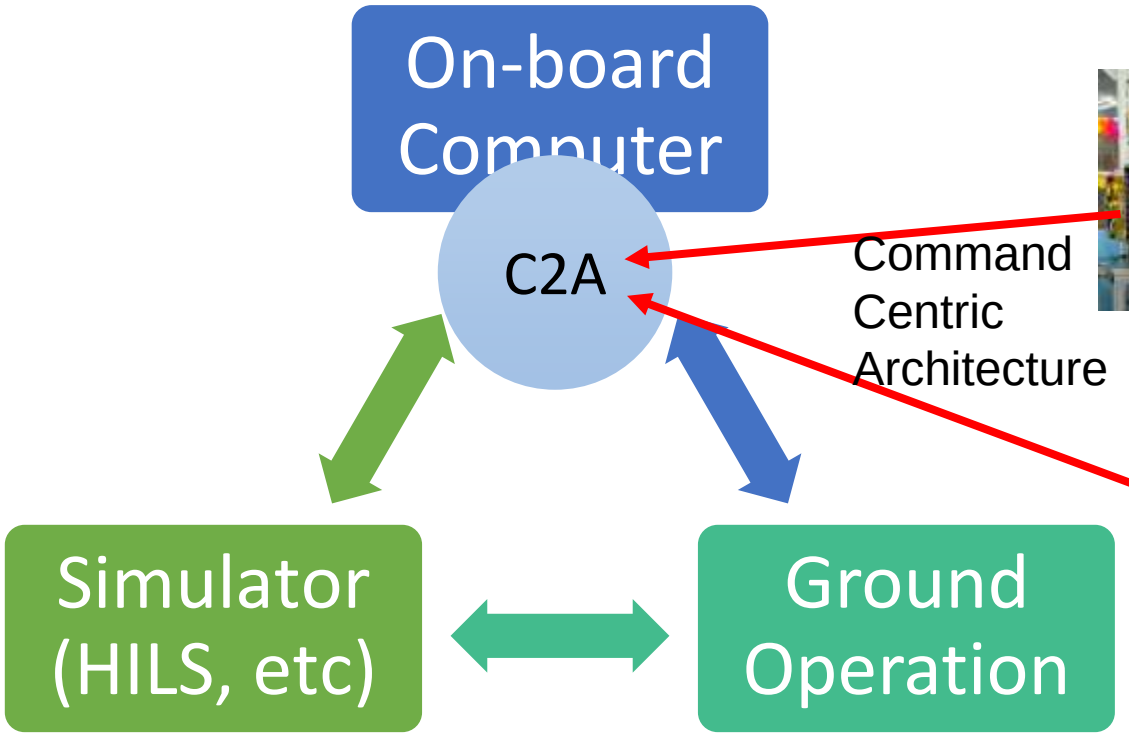
- Software/hardware interface is made open
- Universities voluntarily contribute by providing software which will be shared by community after verification

- "Virtual environment" of satellite, ground station and simulation system (HILS) shared by community
- Verified software can be implemented on satellites
- Existing satellites can be re-used by new software developed by other universities (software test, control algorithm test, new missions, etc.)


PC / Open Source
Virtual Satellite
Simulated
Space Environment
Emulated
Hardware
Software
HILS Satellite
Simulated
Space Environment
Partially
Emulated
Hardware
Software
Real Satellite
Space Environment
Hardware
Software
Seamless
Communication inside PC
Communication by wire
Communication by RF
Software
Emulated
Hardware
Virtual Ground Station
Software
Partially
Emulated
Hardware
HILS Ground Station
Seamless
Software
Hardware
Real Ground Station
Education,
New Algorithm Research,
Early phase software
development & testing
Software development &
testing with real-hardware
in development phase
Real Operation

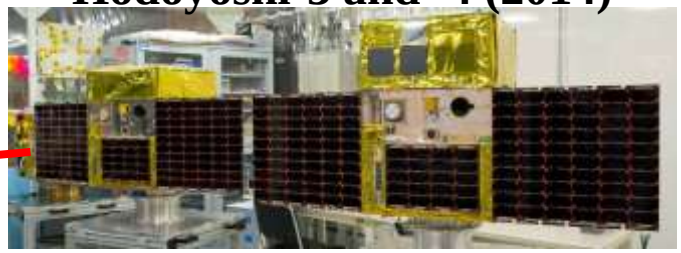
Let us start something !
- A framework for “virtual satellites”-

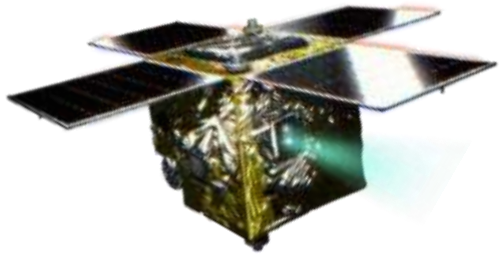
Integrated Satellite Software Framework



Command Centric Architecture

Hodoyoshi-3 and -4 (2014)





PROCYON(2014)
Demonstrated on orbit

This framework will be published as open source activity.

Let us create a community to make a great virtual world!

Guiding Principles for UNISEC-Global

1. Be honest regarding project feasibility – openly recognize technology and schedule risks that may impact success.
2. Evaluate the achievements made in the past, and identify your position in the relation with them.
3. Build a system which can work as designed in the environment where fixing is impossible.
4. Whilst doing your best to avoid failing, ensure that you learn from failure.
5. Setup appropriate and realistic targets commensurate with your capability and capacity.
6. Use imaginative and innovative ways of achieving the maximum using only limited personnel, technical and financial capabilities

7. Identify and work with your rivals and compete with each other to stimulate innovation & mutual growth. Recognize other people's successes and use these to stimulate yourself further.
8. Recognize the pressure in others working to demanding deadlines on challenging projects; support and help reduce their stress wherever possible.
9. Respect a spirit of mutual assistance. Seek ways to contribute to others, not only seeking help for yourself.
10. Evaluate your results realistically and reflect them to your subsequent activities.
11. Be careful not to be misled by the "bewitching nature and allure of space" or by flattering words. Be modest and sincere.
12. Remember that there are rules that you must follow - from internal rules in your project to Outer Space Treaty.

Summary

- CanSat and Micro/nano/pico-satellites are excellent materials for space education as well as systems engineering/project management
- Start from simple space systems !
- Low cost and quick development micro/nano/ pico-satellites are opening new ways of space development and utilization.

- Please establish a community and make the most of community power!
- Let us start some “UNISEC-GLOBAL” projects !