
PROCYON '14

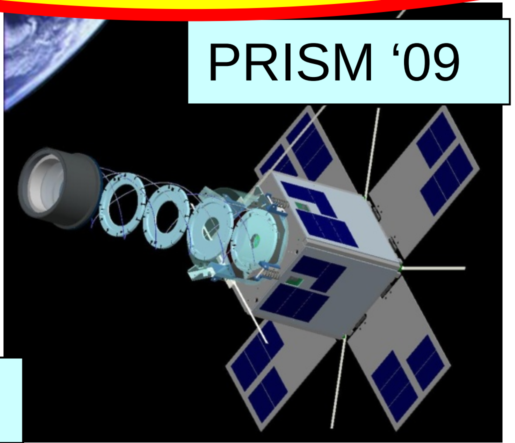

Hodoyoshi-1 '14

# Small and Micro/nano-satellite Possibilities in Space Science and Exploration - Examples from Japan -


**Shinichi Nakasuka and Ryu Funase**
**University of Tokyo**



CubeSat 03,05


PRISM '09

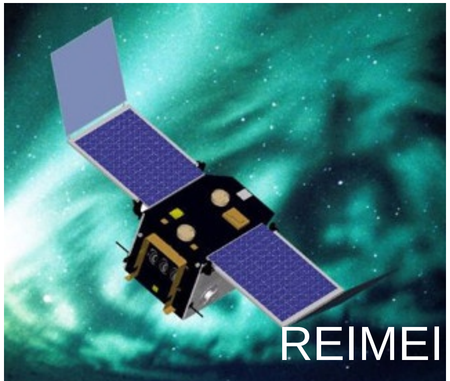

Nano-JASMINE '17

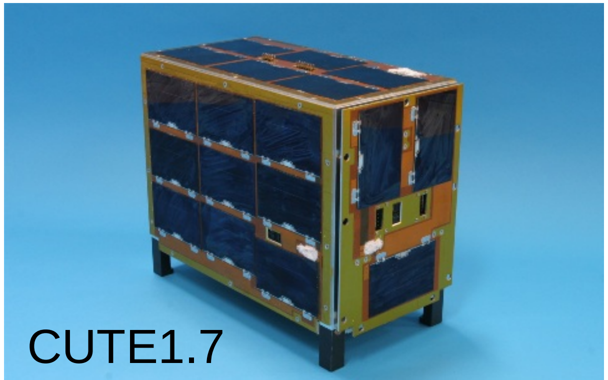
# Overview and Contents

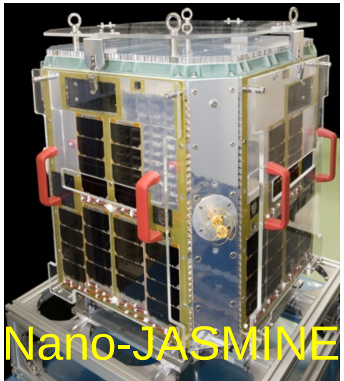
- Three streamlines of space science and exploration projects in Japan
  1. JAXA/ISAS has excellent history of space sciences using small-large(3t) satellites
  2. Universities started own contributions using micro/nano/pico-satellites (since 2003)
  3. University-JAXA joint missions for space exploration started in 2013 with PROCYON
- University of Tokyo's contributions in micro/nano/pico-satellite fields
- Key strategies to pursue science missions using small/micro/nano/pico-satellites

# Space Science and Exploration
# - Japanese Missions and Players -

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



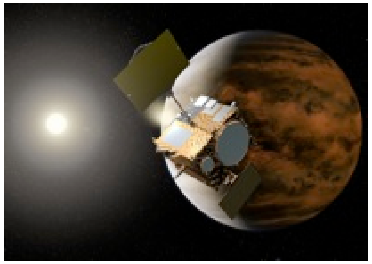



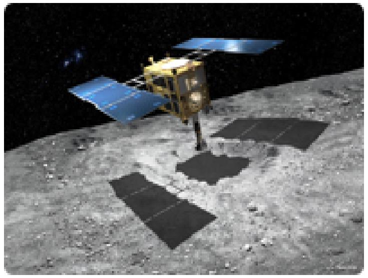

# JAXA: “Larger than small-satellite” Exploration Projects

Kaguya: Japanese first lunar orbiter. Improved global topography maps, global gravity map and observation of shadowed interior of the crate, etc (**2.9t**, launch 2007)

Hayabusa :Challenging space technology demonstration leading to the birth of a new pillar in planetary sciences. Returned and asteroid dusts obtained, and samples are under investigation. (**510kg**, launch 2003, return 2010)



Akatsuki : Understanding the atmospheric dynamics and cloud physics of Venus, Succeed in inserting into Venus orbit in Dec 2015. (**500kg**, launch 2010)

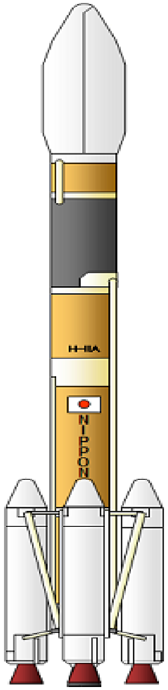


Hayabusa2: Targeting at an asteroid whose samples enable us to address the ultimate science question related to our origin. (**600kg**, launch Dec 2014)

# JAXA/ISAS’s Small Satellite Space Science Program (300～600kg)

# JAXA/ISAS Strategy for Space Science Programs

Space Science Projects are becoming more & more diversified




**ISAS strategic mission (cost: $200M-300M)**

**Flagship mission to be led by big Japanese communities with large-scale world-wide collaboration (H-2A Rocket)**

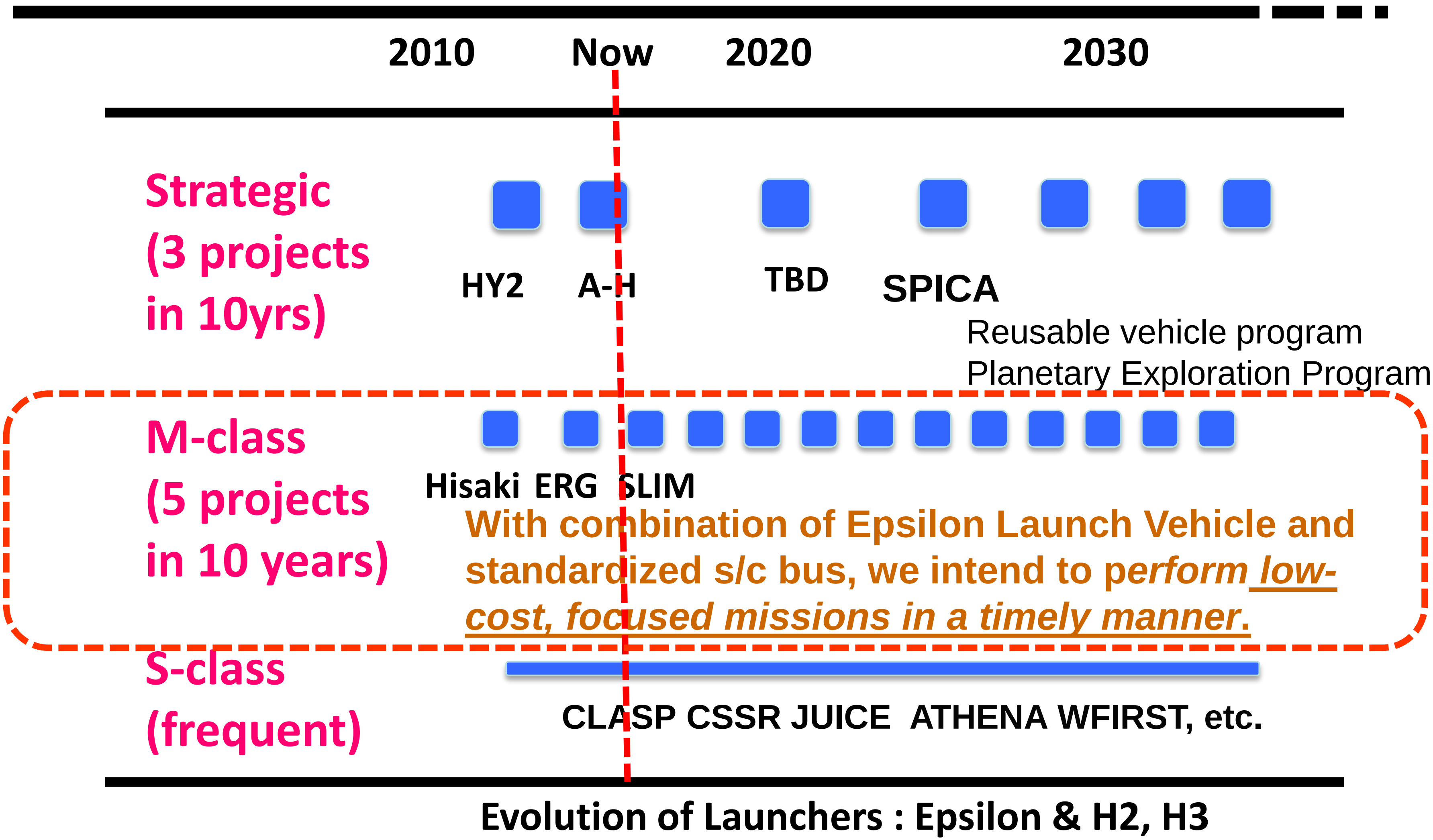
**M-class mission (300-600kg size) (< $100M)**

**Has more focused, challenging missions. Frequent opportunities provided with lower cost and Epsilon launch. Also including planetary exploration using "enhanced Epsilon".**

**S-class mission (<$10M)**

**Missions with science payload development which will be onboard on foreign missions, or small projects using balloons, sub-orbital rockets and micro-satellites.**

# ISAS Space Science Roadmap




Project cost range (rough image)

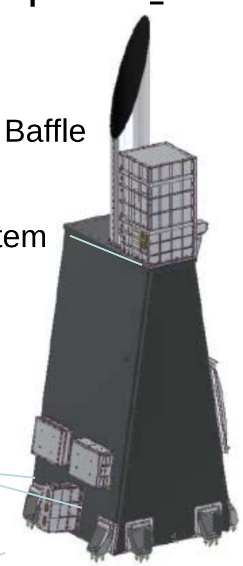
Strategic: \$200-300M  M-Class: around \$100M  S-Class: <\$10M

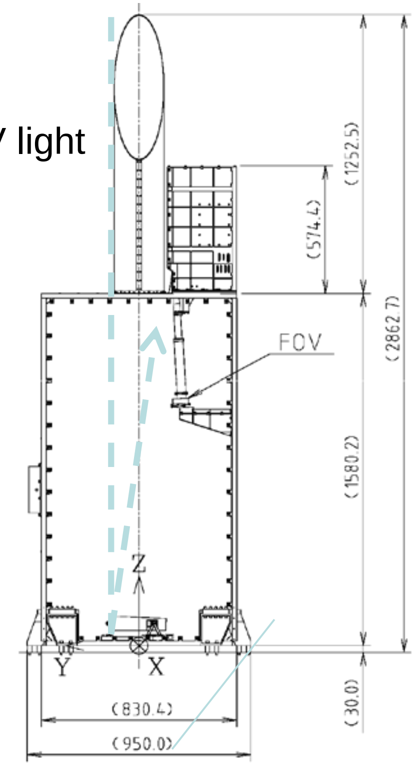
# M-Class (1): SPRINT-A/EXCEED (HISAKI)

**Launched on 14 Sep. 2013 (335kg) on first Epsilon rocket launch**

- **Ex**treme ultraviolet spectros**C**ope for **E**xosph**E**ric **D**ynamics
- The mission is spectroscopic and imaging observation of EUV (extreme ultraviolet: 60-145nm) emissions from tenuous plasmas around ***Venus, Mars, Mercury, and Jupiter***.
  - ➢ measuring the plasma escape rates from the terrestrial planets (Venus, Mars, and Mercury)
  - ➢ understanding the electron energy and density distribution around the Jovian inner magnetosphere.

SPRINT-A/EXCEED



# M-class (2) ERG (Energization & Radiation in Geospace)

**Planned to be launched in FY2016 (350kg)**

ERG is a mission to elucidate acceleration and loss mechanisms of relativistic electrons of Van Allen belts during space storms.

**Significance of the project:**

- Direct observations on generation of relativistic electrons at the magnetic equator in the inner magnetosphere
  → contribution to understanding of the particle acceleration.
- Instrumental development to measure plasma and fields under the incidence of radiation belt particles with small satellite
  → contribution to a future Jovian mission.
- Understanding the acceleration and loss mechanisms.
  → contribution to predictable space weather model for space radiation environments.

# M-class (3) SLIM (Smart Lander onto the Moon)

**Planned to be launched in FY2019 (520kg)**

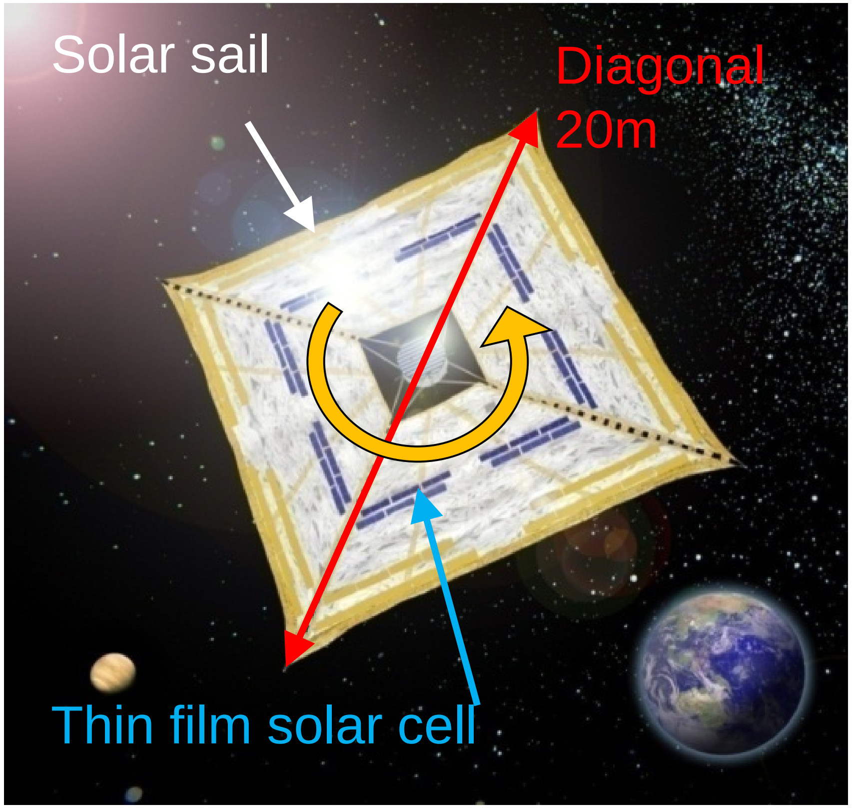
SLIM is a mission to demonstrate the technology for pin-point (about 100m accuracy) soft landing on lunar surface.

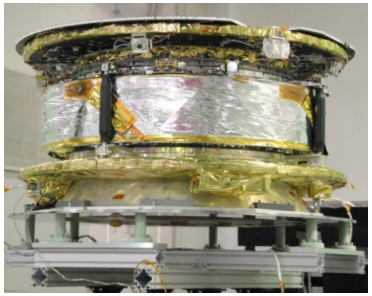
- Technology demonstration with Small Spacecraft
  - Image-based Navigation utilizing Lunar Terrain
  - Autonomous Obstacle Detection
  - Robust Pin-point Guidance
  - Landing Shock Absorber
  - High-performance Propulsion
  - Exploration using Spectrimeter or Tiny Rovers (option)
- Frequent trials of lunar/planetary surface exploration technology
- Precursor of future full-scale lunar or planetary missions

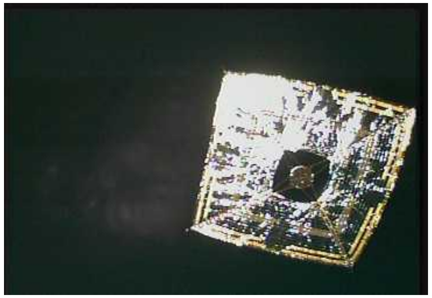
# (Piggy-back) IKAROS: A Solar Sail Demonstrator

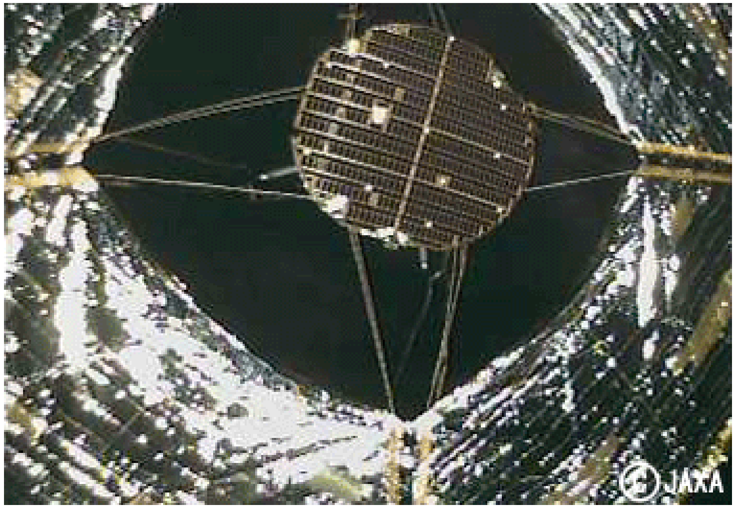
**IKAROS** (= **I**nterplanetary **K**ite-craft **A**ccelerated by **R**adiation **O**f the **S**un) is the world's first interplanetary solar sail craft which demonstrated its photon sailing and thin film solar power generation

- (**310kg**, launch 2010 as piggyback)



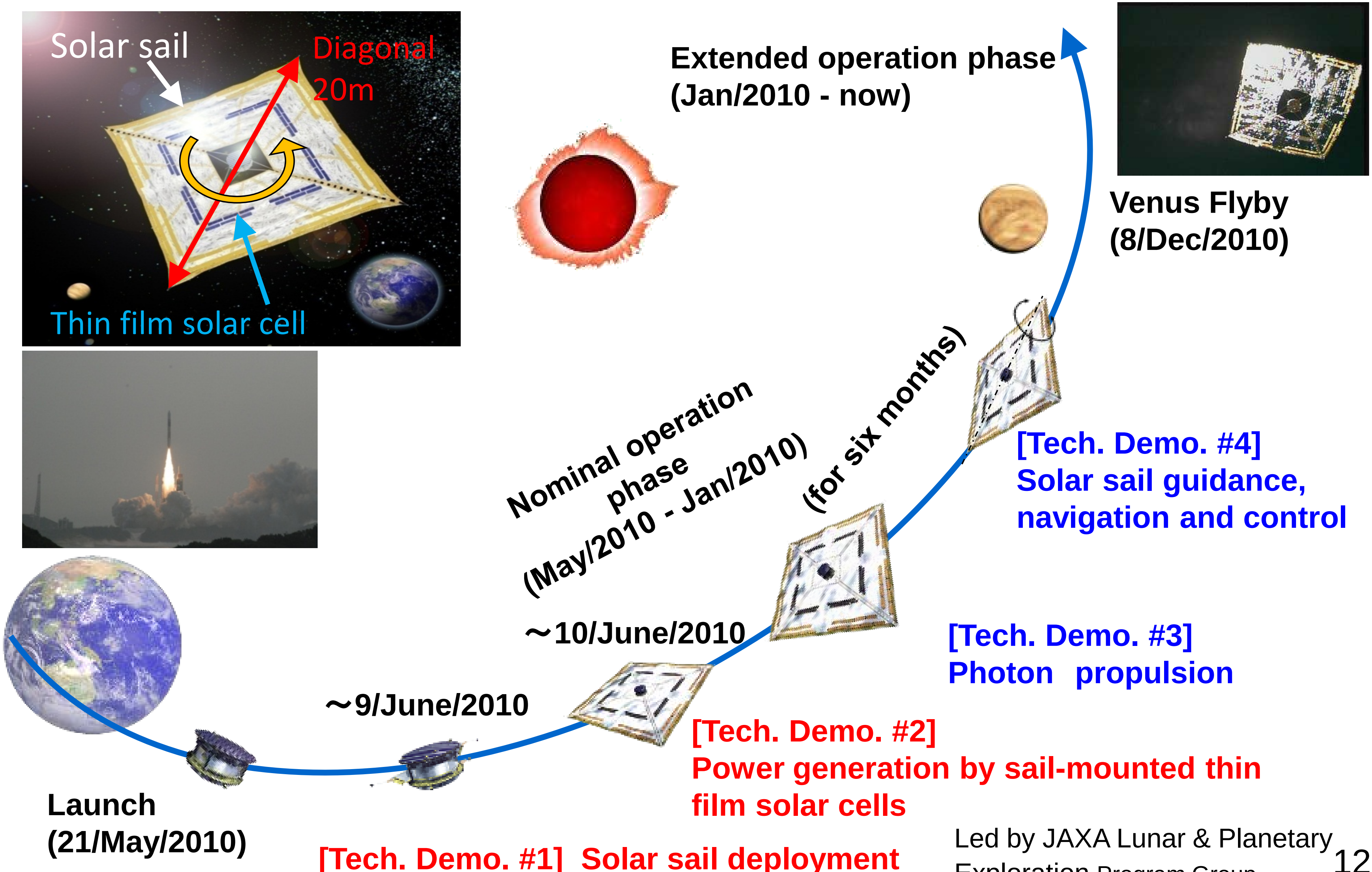








**DCAM(Camera-craft) captured solar-sailing IKAROS June 14, 2010**

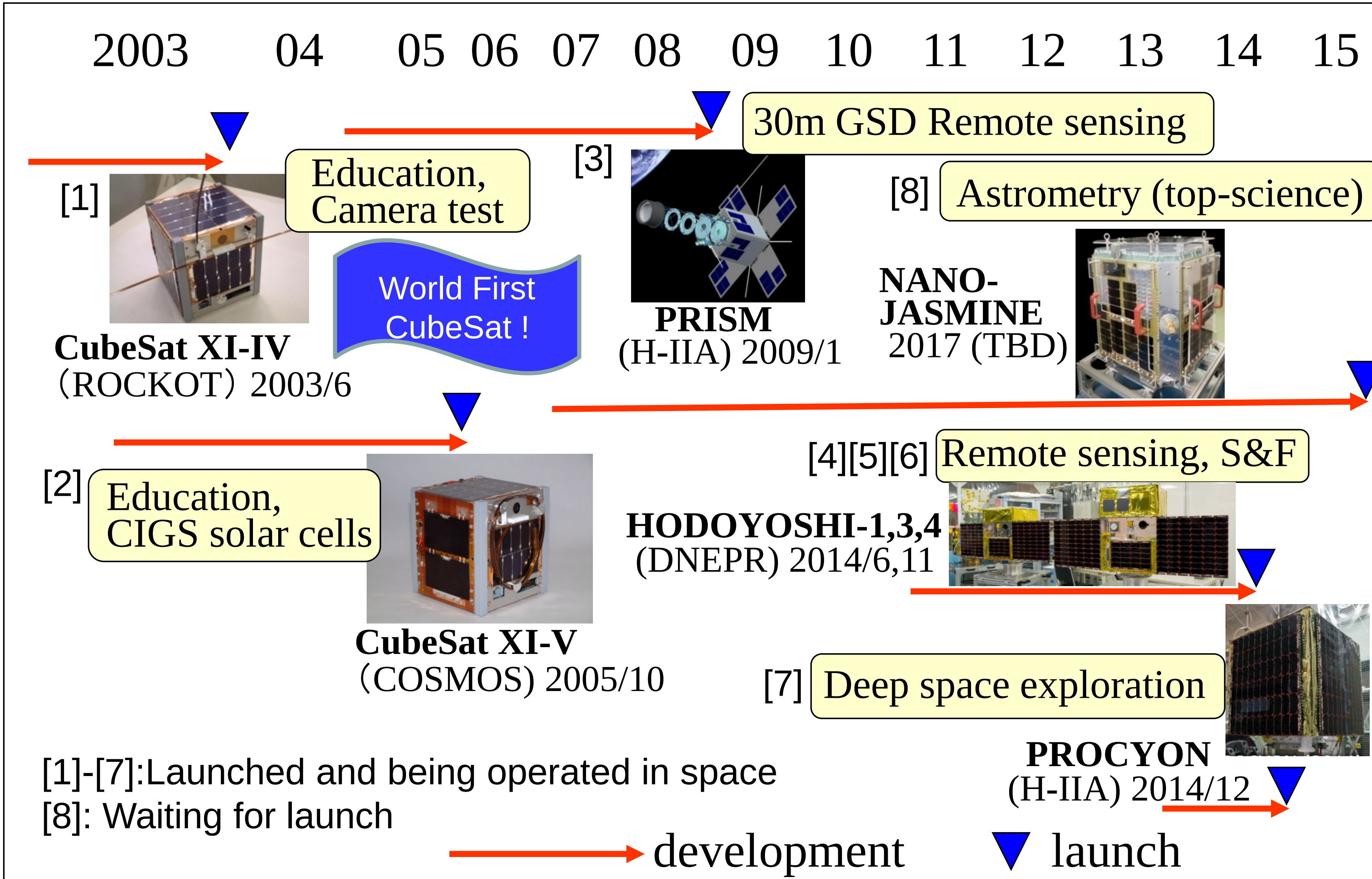
# IKAROS Succeeded in Solar Sailing (2010)




Led by JAXA Lunar & Planetary Exploration Program Group

# Micro/nano/pico-satellite space science/exploration projects driven by universities （1～100kg）

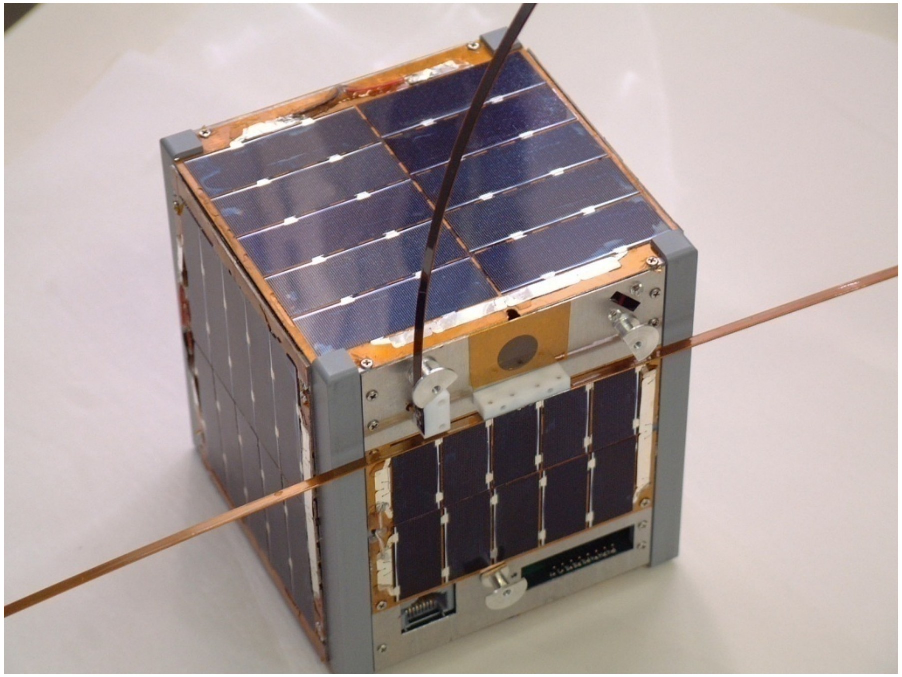
# University of Tokyo's (UT's) History - 8 satellites developed (7 launched) -



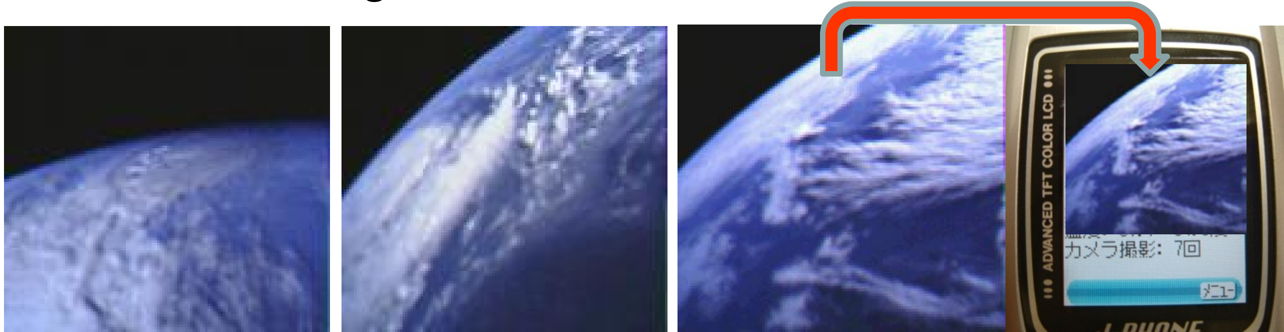
# CubeSat “XI-IV (Sai Four)”

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 |
| Expected life time | ?? |



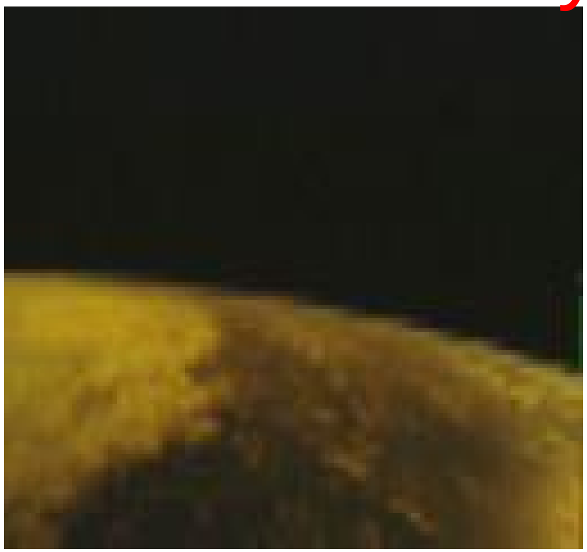
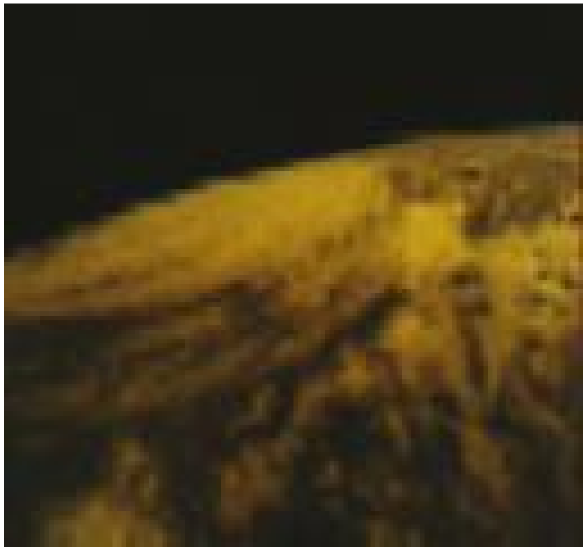
Captured Earth Images are Distribution to Mobile Phones



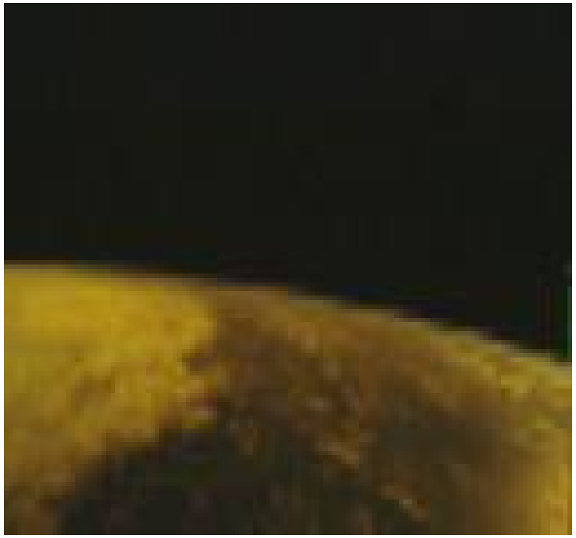
# XI-IV is still perfectly working after 13 years in orbit

## Recently Downlinked Photos

Sepia color !
Get older ?





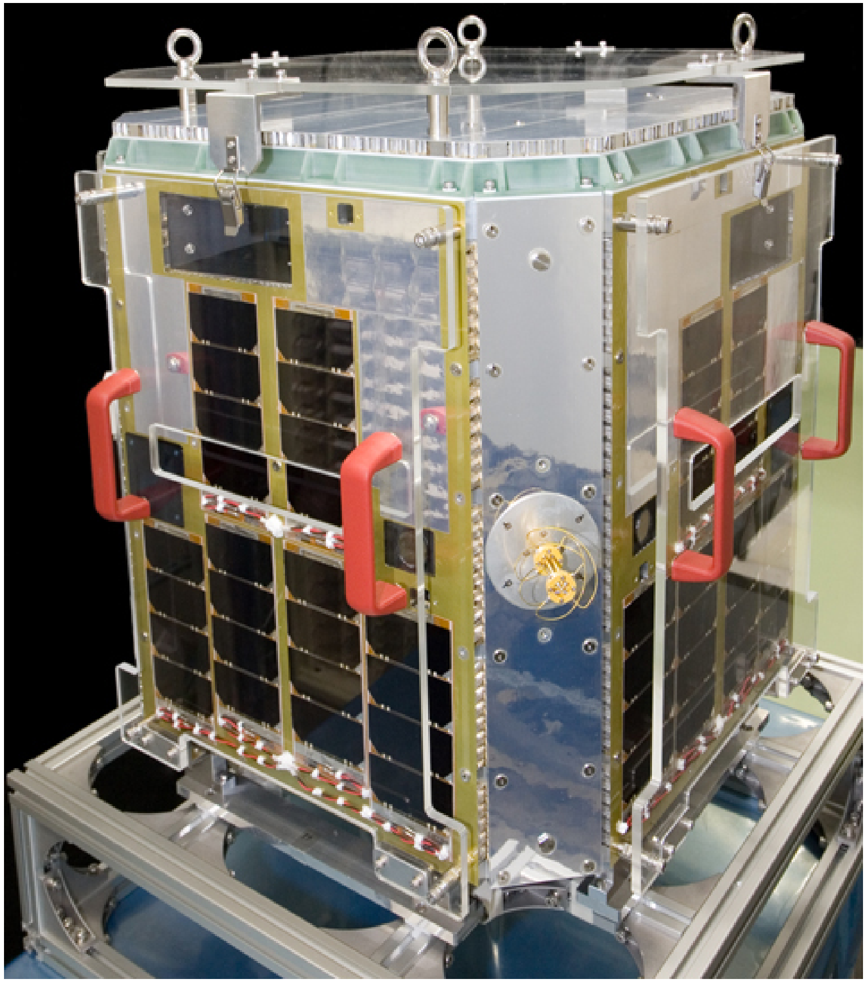
# UT's 4th Satellite:Nano-JASMINE

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: 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] |

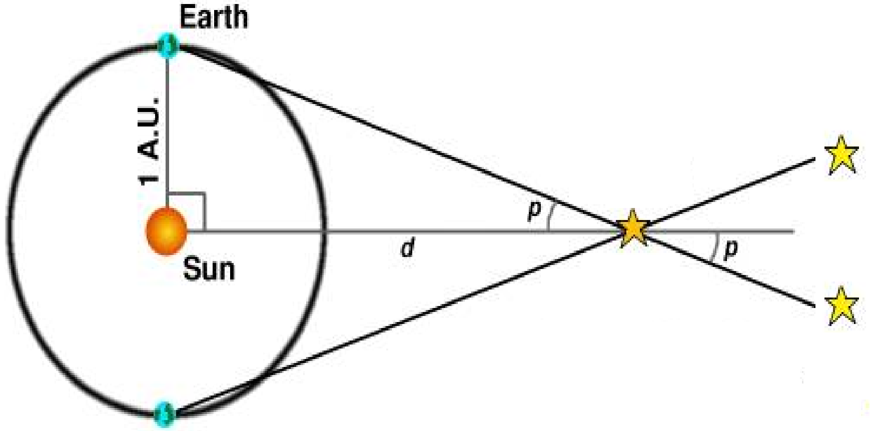
Special features:

| | |
|---|---|
| -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 Dimensional positions of stars and their movement ("Astrometry")**
  - **Pre-cursor for "JASMINE" series**



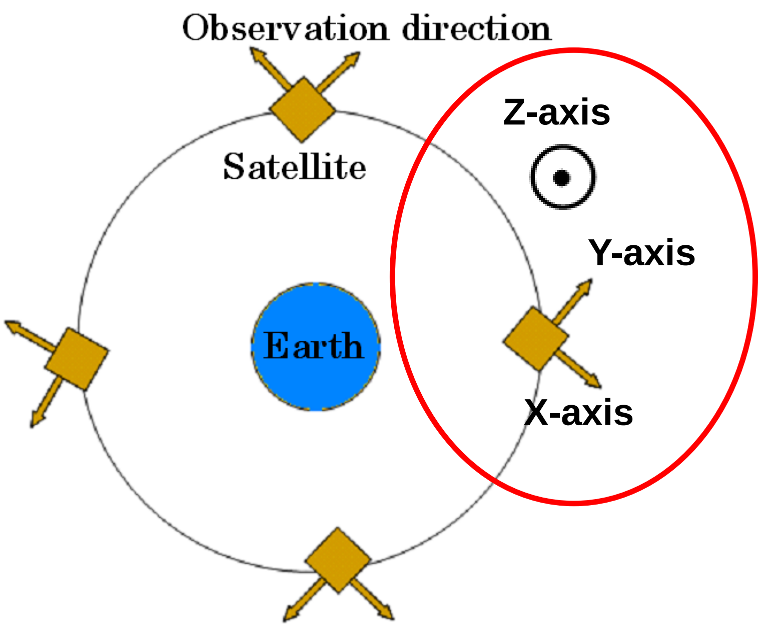

**Star position determination by**
**Annual Parallax**

- **Attitude stabilization 0.8 arcsec / 8.8s**
- **Temperature stability**
  - **50℃, ±0.1℃**

- Long exposure time required.

- Separation angle between two telescopes should be kept constant.

# Star Observation using TDI



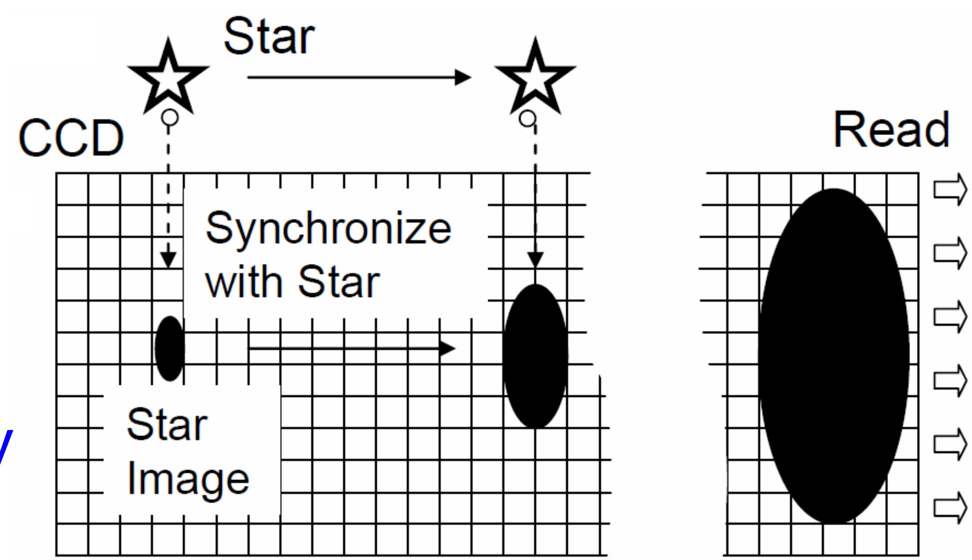

**Time Delayed Integration (TDI) using special CCD sensor**

**Spin rate is synchronized to capacity transfer speed on CCD to get long exposure time**

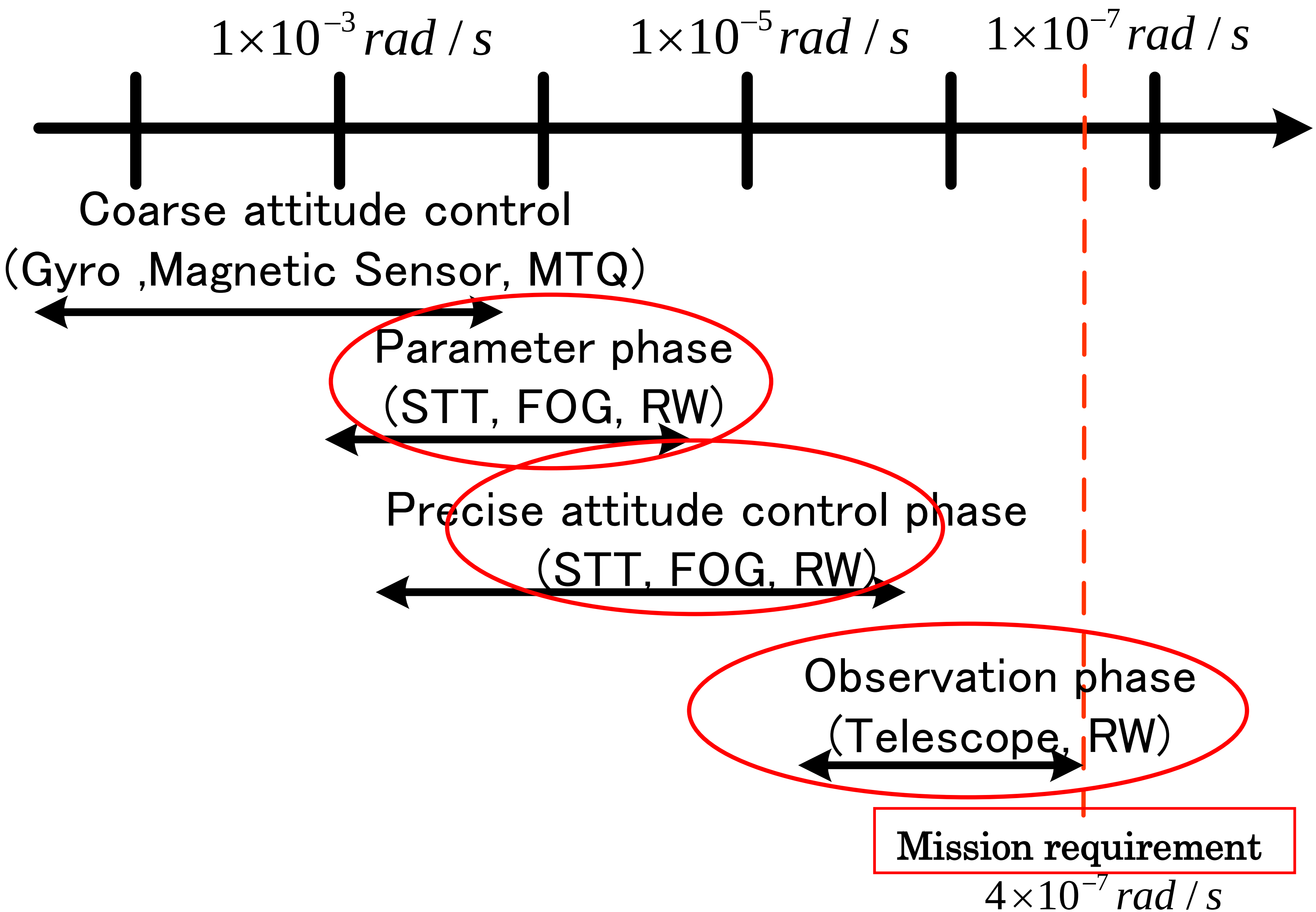
**X, Y->Observation direction**

**Z-> Spin axis in orbital period**

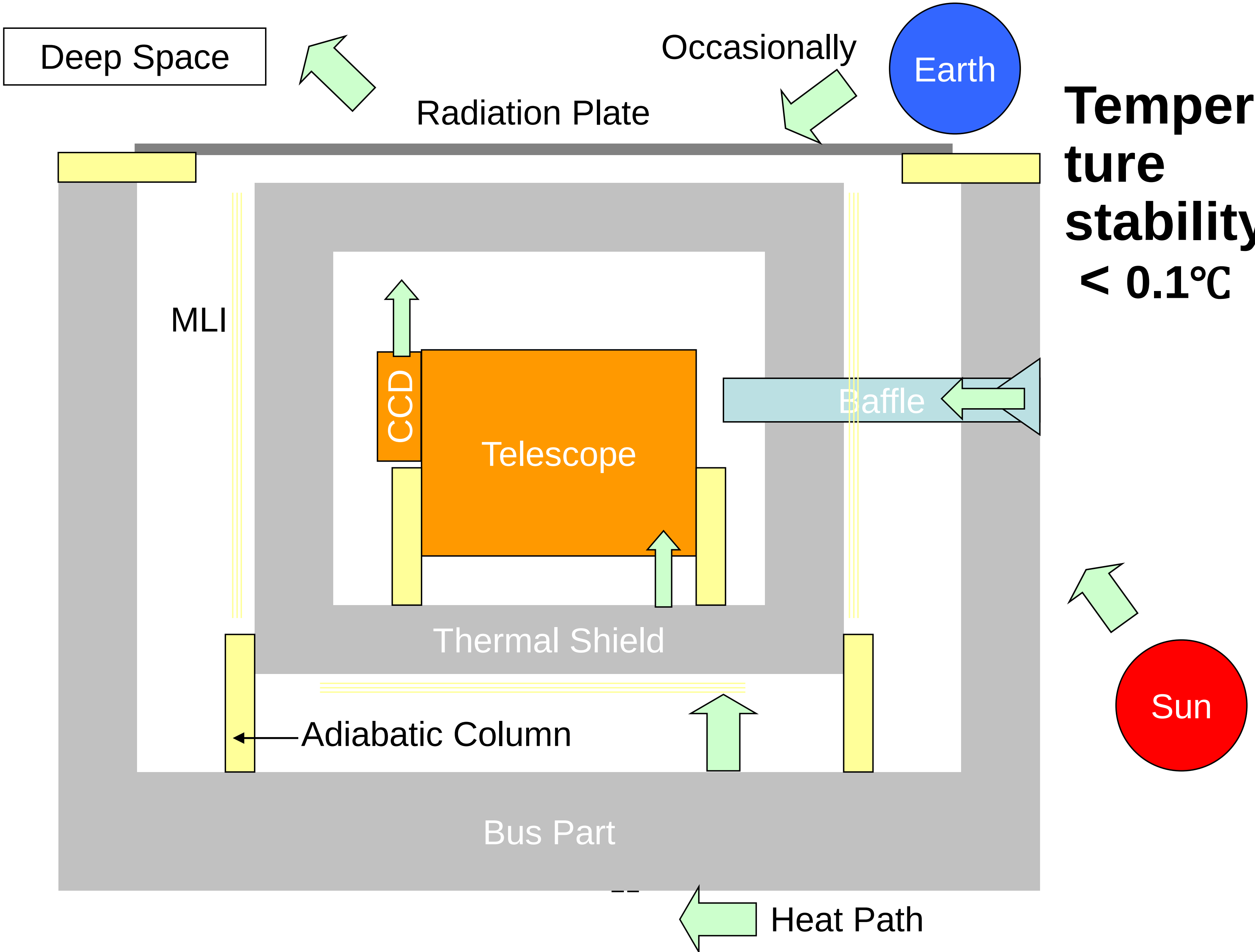
4 x $10^{-7}$ rad/sec level stability is required



# Strategy to Achieve High Attitude Stability

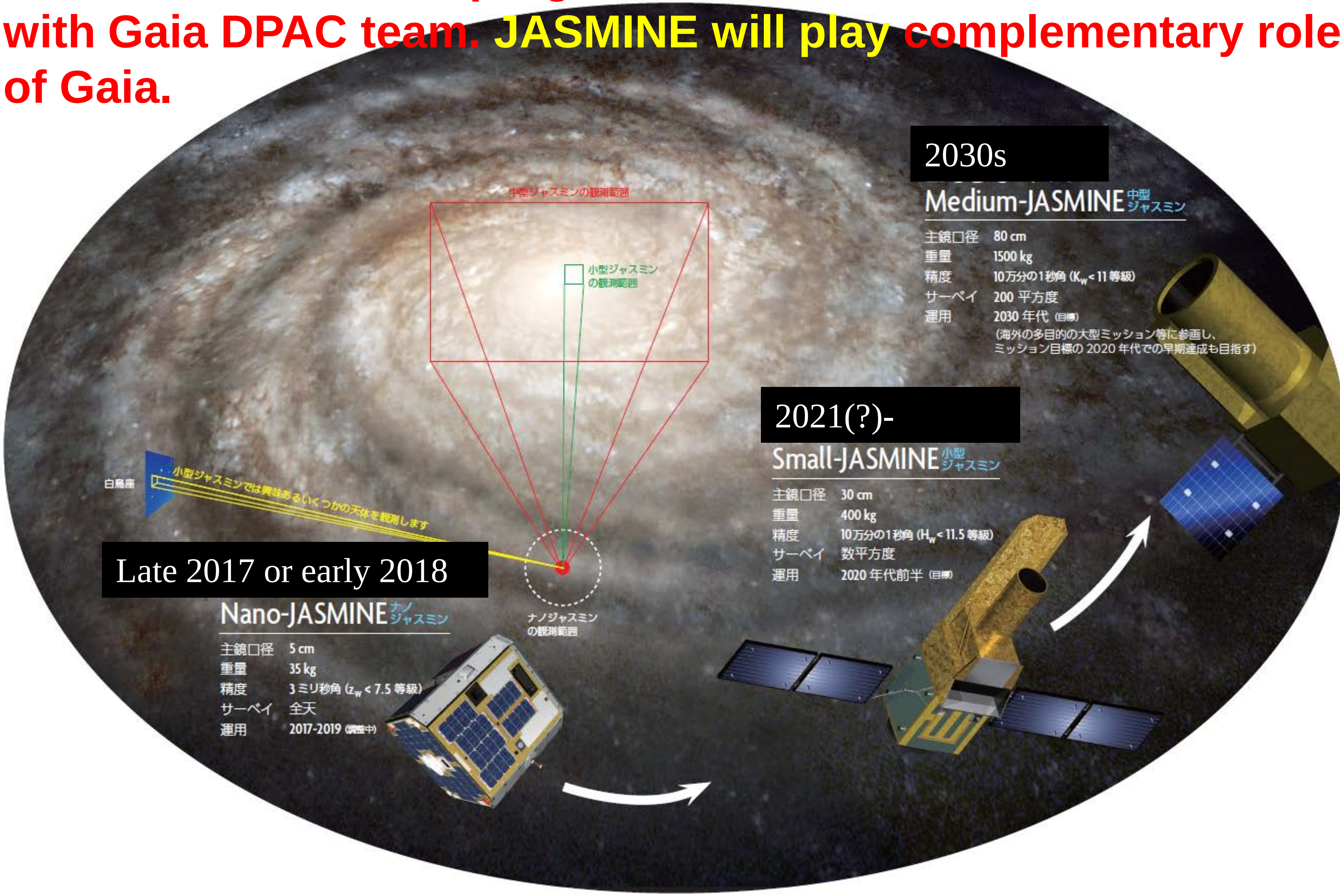


# Sever Thermal Stability is Achieved by:




**Tempera-ture stability < 0.1℃**

**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.**



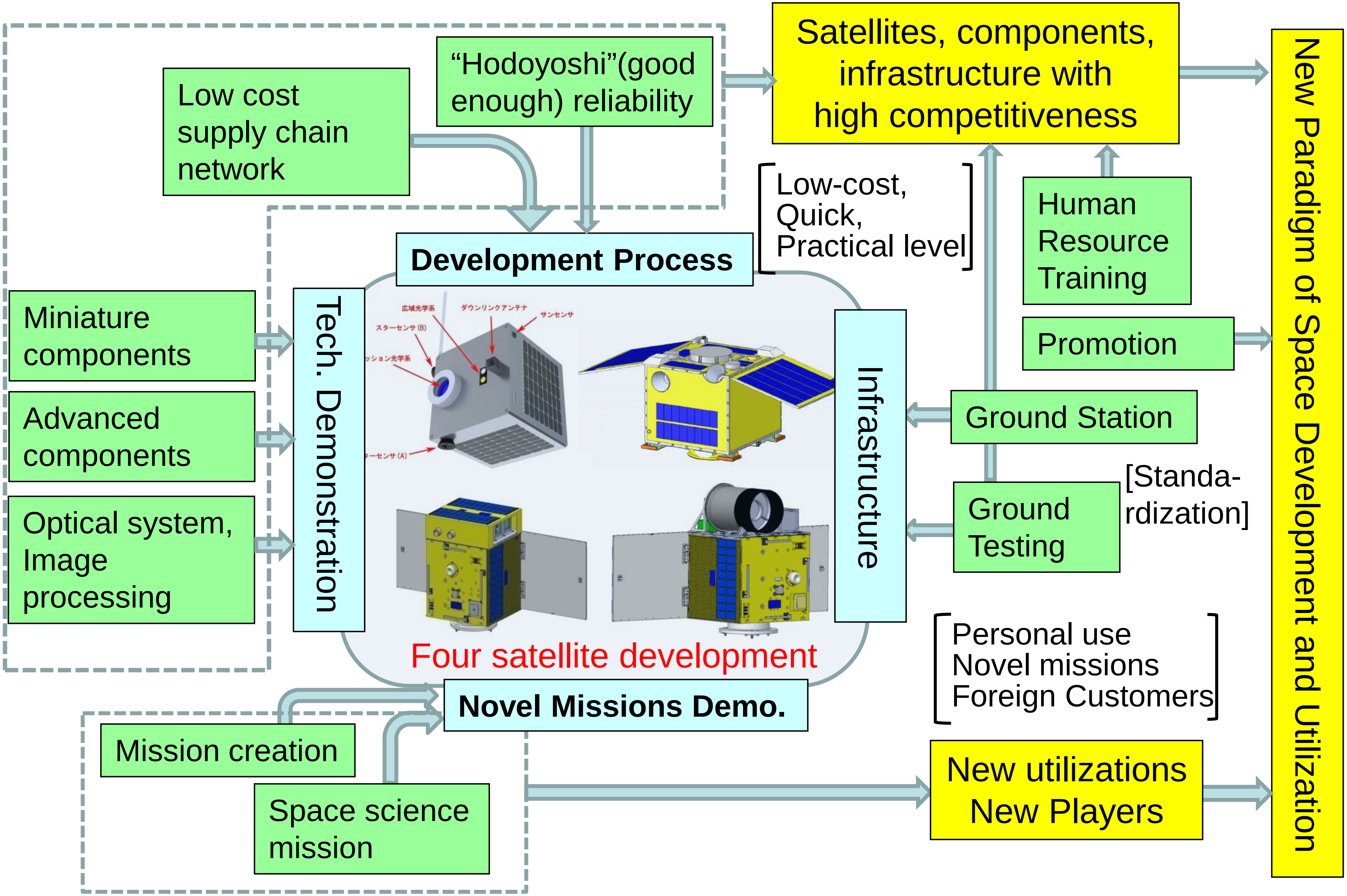
# University Satellites in Japan

## 37 university satellites launched in 2003-2015


From CanSat to CubeSat, Nano-Satellite

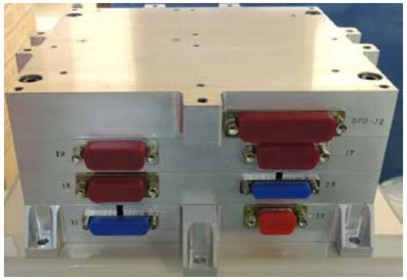
From Educational purpose to Practical applications

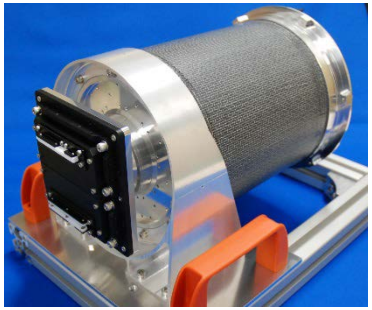
# “Hodoyoshi-Project” to Establish Infrastructure for Micro-satellites in Japan (‘10-’14)



# Components Developed (examples)

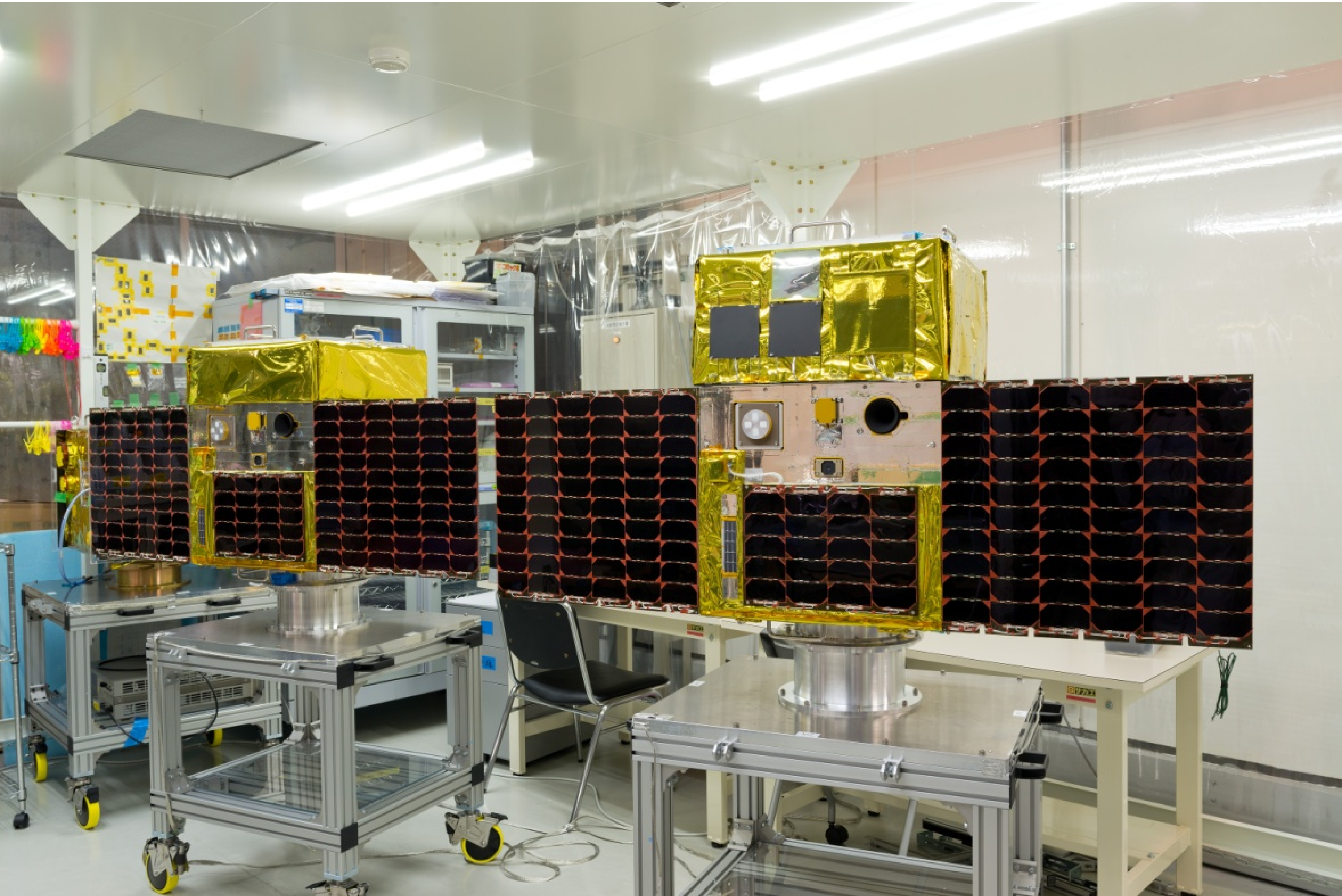
- Radiation-hardened SOI-SoC onboard computer
- Software architecture (SDK, HILS, etc.)
- Optical camera with 2.5 - 200m GSD
- Li-Ion battery and power control unit
- Low-shock lock/release & deployable mechanism
- High speed and versatile data handling unit
- High speed, low power RF transmitter （>500Mbps)
- 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)





Supply chain of 170 companies re-established to reduce cost

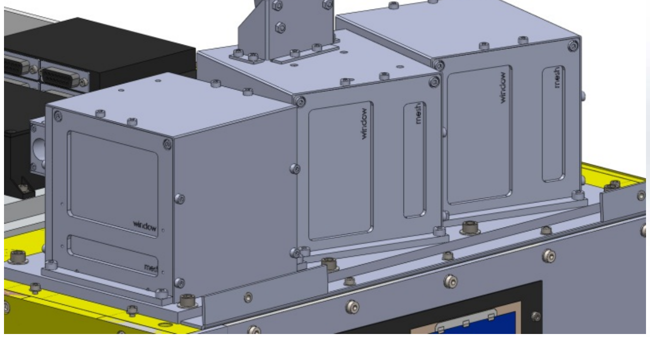
# Hodoyoshi-3 (left) and Hodoyoshi-4 before Shipment (April, 2014)

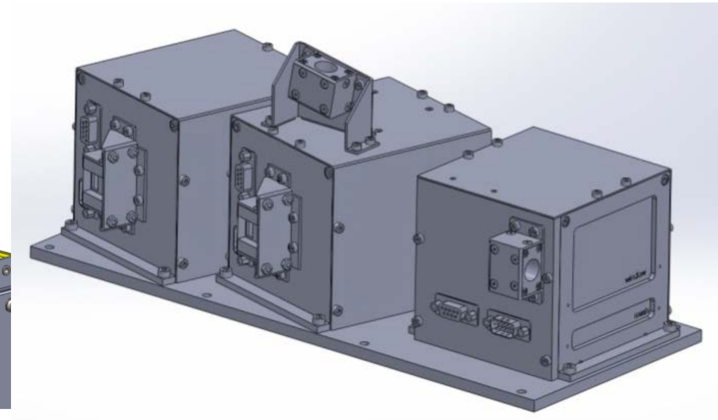



Chiba（6m GSD)
Hodoyoshi-4
(66kg)

Dubai (6.7mGSD)
by Hodoyoshi-1
(60kg)
©AXELSPACE

# "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.

# HODOYOSHI-2（RISESAT)

**International Space Science Platform**

**Size:**
50cm
55kg

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

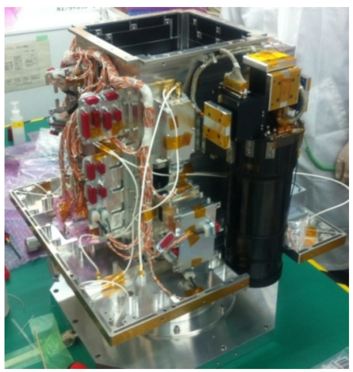
**Power:**
100W

**ACS:**
<0.1°

**Rocket: Epsilon**

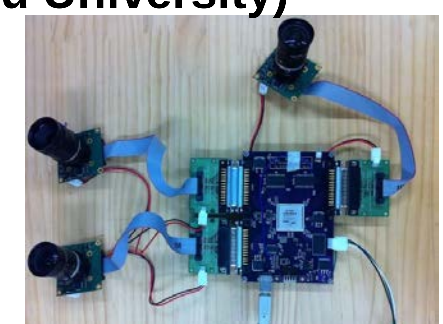
2018 launch

**High Precision Telescope- HPT (Taiwan/Vietnam)**



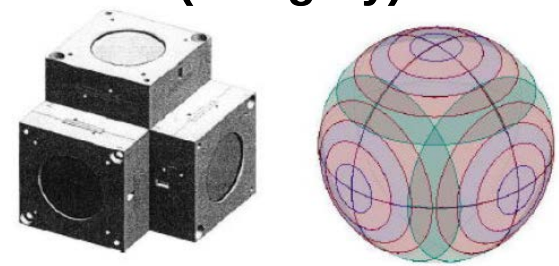
**Meteor counter - DOTCam (Taiwan(NCKU))**

**Ocean Observation Camera - OOC (Tohoku University)**

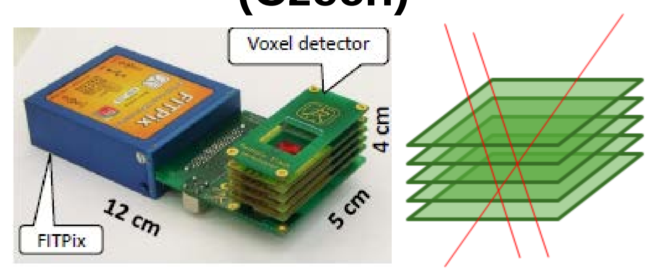


**Camera Instruments**

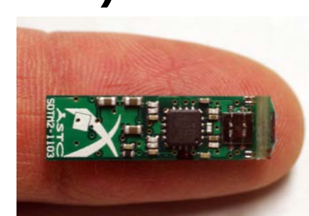
**TriTel – 3D Dosimeter (Hungary)**



**TIMEPIX – Particle counter (Czech)**




**SDTM – MEMS Magnetometer (Sweden)**

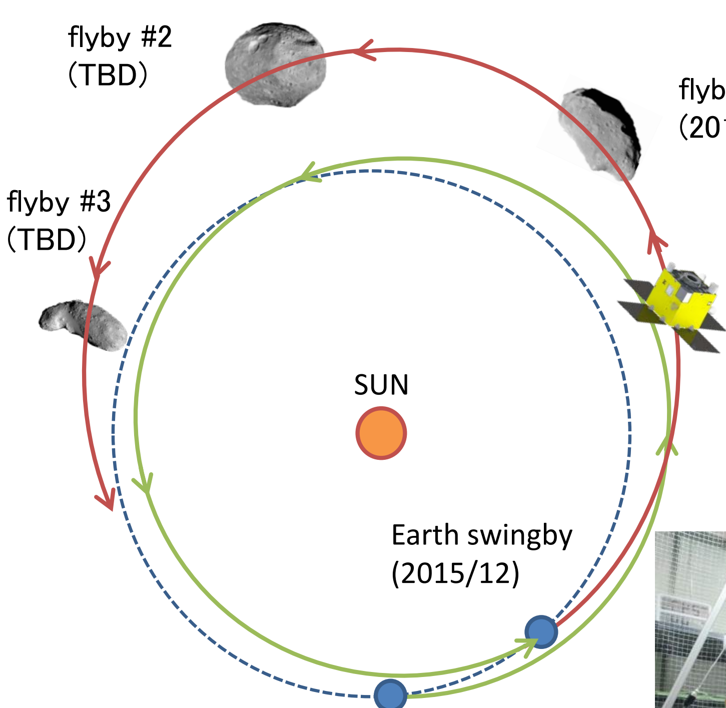


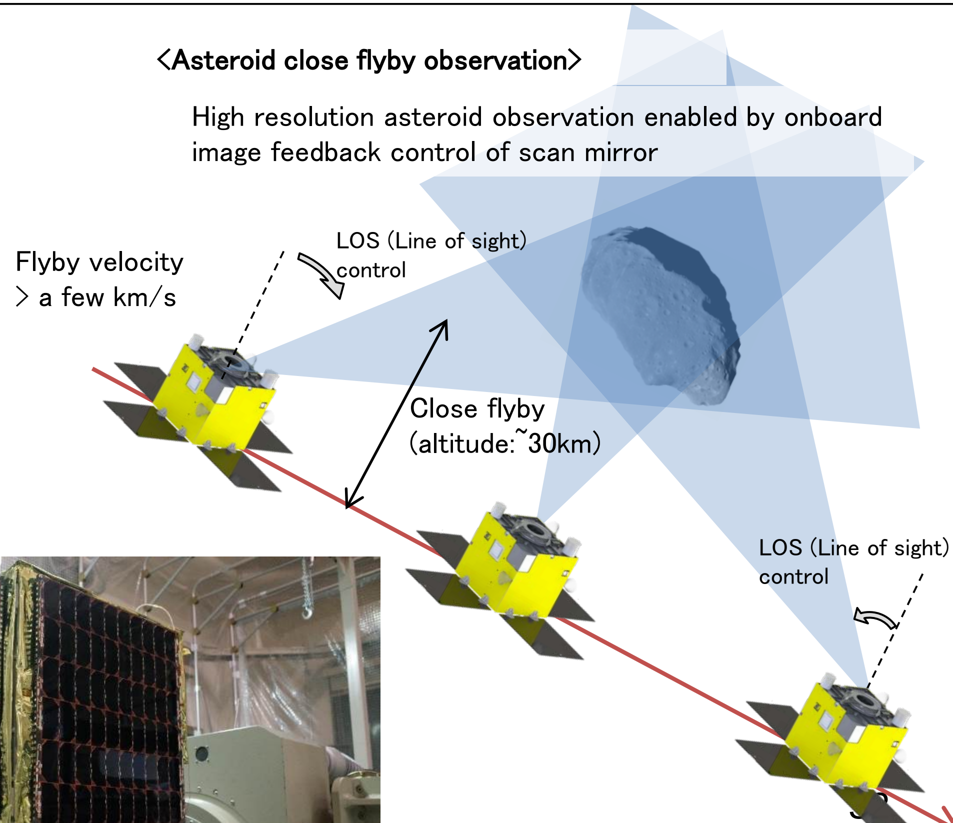
**Sensor Instruments**

# 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)



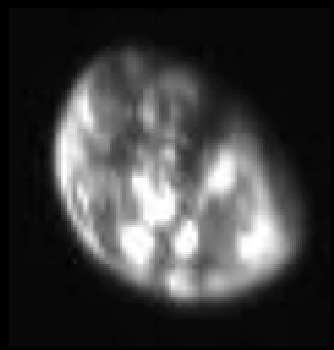

**Launched (2014/12, together with Hayabusa-2 asteroid explorer)**

Used Hodoyoshi compo.
Developed within 1.2 years

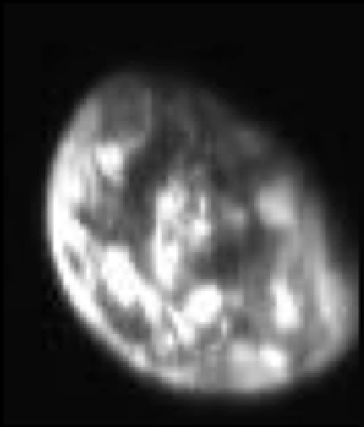
# Earth photos captured from deep space by PROCYON

2015/11/08
@ 11,000,000
km away

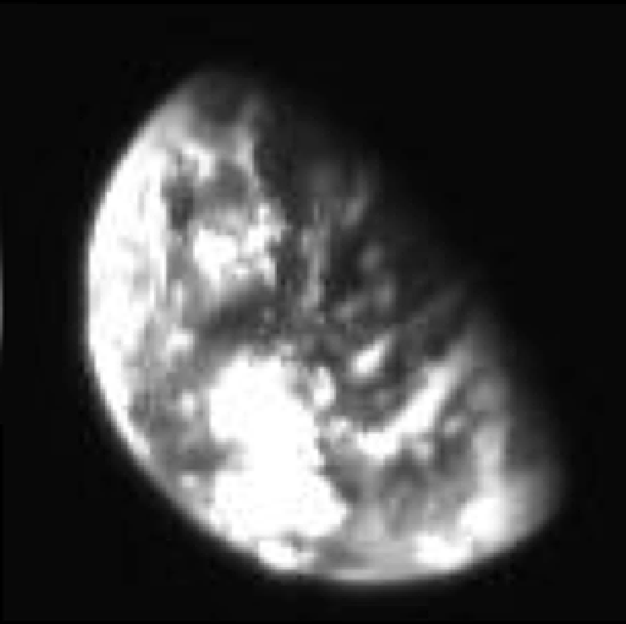
2015/11/16
@ 8,000,000
km away



2015/11/18
@ 6,800,000
km away



2015/11/23
@ 5,200,000
km away



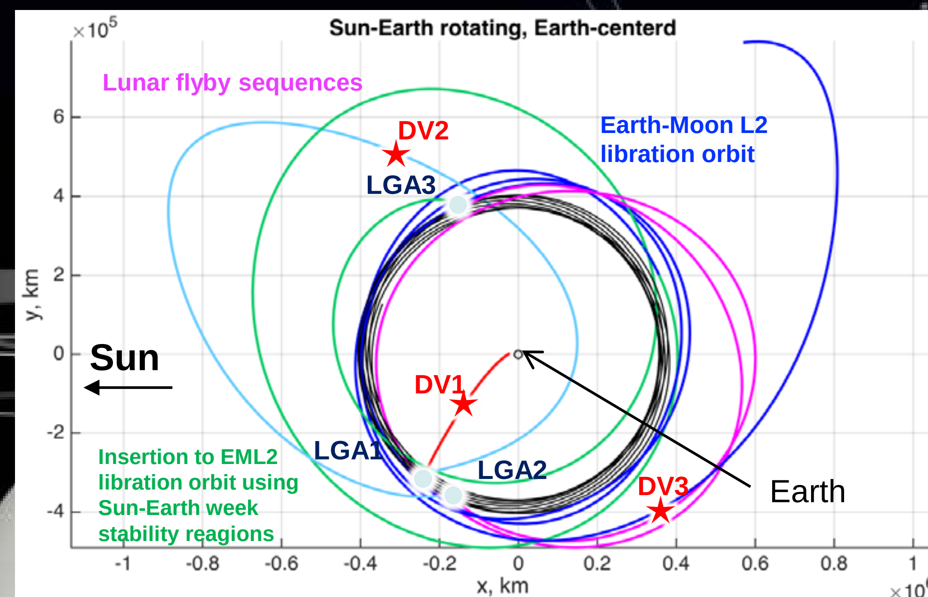
2015/11/29
@ 3,300,000 km away

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

For detail,
Tuesday 8:45am by Ryu Funase

# 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

# Key Strategies

- Small-satellite size (<500kg) can aim at world top science. **How to assure frequent opportunity** is the key issue. Key strategies include:
  - Low-cost standard bus or standard design process ?
  - Low-cost launcher (dedicated launch/piggyback ?)
  - Selection of "mission level" considering cost-performance
- Micro/nano-satellite (<100kg) is very promising as:
  - Precursor mission leading to larger sized missions ("program" including several step-uping missions)
  - Excellent opportunity for human resource training
  - Some projects can even aim at top science in niche areas
- Collaboration between Space Agency-Universities has many merits

# 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 start, it would be hard to start as it is very difficult to get the public approval and funding.

*Quickly start with “not perfect” but “good enough” science mission!*

# METI launches “JAPAN BOOTH” at SSC 2016

- Japanese Ministry of Economy, Trade and Industry (METI) has launched <u>**“JAPAN BOOTH”**</u> at <u>**West Colony**</u>.
  - 21 Japanese companies and universities join.
- <u>**The Portal Website (Makesat.com)**</u> has just been released.
  - [https://makesat.com](https://makesat.com)