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

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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 -

<table>
<thead>
<tr>
<th>Size(kg)</th>
<th>Category</th>
<th>Players</th>
<th>Project Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;500</td>
<td>Mid-large</td>
<td>JAXA</td>
<td>Science: Ginga, Akari, Suzaku, Hitomi—Exploration: Hayabusa &amp; 2, Kaguya, Akatsuki--</td>
</tr>
<tr>
<td>2-20</td>
<td>Nano</td>
<td>University</td>
<td>Science: CUTE-1.7+APD II (3kg 2008) Exploration: ECUULEUS (6U EM-1 2018)</td>
</tr>
<tr>
<td>&lt;2</td>
<td>Pico</td>
<td>University</td>
<td>Science:</td>
</tr>
</tbody>
</table>
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)
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

Strategic
(3 projects in 10 yrs)

2010
HY2
A-H

Now

2020
TBD
SPICA

2030

M-class
(5 projects in 10 years)

Hisaki ERG SLIM

With combination of Epsilon Launch Vehicle and standardized s/c bus, we intend to perform low-cost, focused missions in a timely manner.

S-class
(frequent)

CLASP CSSR JUICE ATHENA WFIRST, etc.

Evolution of Launchers: Epsilon & H2, H3

Reusable vehicle program
Planetary Exploration Program

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

- Extreme ultraviolet spectrosCope for ExosphEric Dynamics
- 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.
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 Spectrometer or Tiny Rovers (option)

- Frequent trials of lunar/planetary surface exploration technology
- Precursor of future full-scale lunar or planetary missions
IKAROS (= Interplanetary Kite-craft Accelerated by Radiation Of the Sun) 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)
IKAROS Succeeded in Solar Sailing (2010)

- [Tech. Demo. #1] Solar sail deployment
- [Tech. Demo. #2] Power generation by sail-mounted thin film solar cells
- [Tech. Demo. #3] Photon propulsion
- [Tech. Demo. #4] Solar sail guidance, navigation and control

Launch (21/May/2010)

Extended operation phase (Jan/2010 - now)

Venus Flyby (8/Dec/2010)

Nominal operation phase (May/2010 - Jan/2010) (for six months)

~9/June/2010

~10/June/2010

Thin film solar cell

Solar sail

Diagonal 20m

Led by JAXA Lunar & Planetary Exploration Program Group
Micro/nano/pico-satellite space science/exploration projects driven by universities (1~100 kg)
University of Tokyo’s (UT’s) History
- 8 satellites developed (7 launched) -

[1] CubeSat XI-IV (ROCKOT) 2003/6

Education, Camera test

World First CubeSat!


Education, CIGS solar cells

[3] PRISM (H-IIA) 2009/1

30m GSD Remote sensing

[4][5][6] HODOYOSHI-1,3,4 (DNEPR) 2014/6,11

Remote sensing, S&F

[7] NANO-JASMINE 2017 (TBD)

Astrometry (top-science)

[8] PROCYON (H-IIA) 2014/12

Deep space exploration

[1]-[7]: Launched and being operated in space

[8]: Waiting for launch

[3]-[7]: Development

launch
**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

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>10x10x10[cm] CubeSat</td>
</tr>
<tr>
<td>Weight</td>
<td>1 [kg]</td>
</tr>
<tr>
<td>Attitude control</td>
<td>Passive stabilization with permanent magnet and damper</td>
</tr>
<tr>
<td>OBC</td>
<td>PIC16F877 x 3</td>
</tr>
<tr>
<td>Communication</td>
<td>VHF/UHF (max 1200bps) amateur frequency band</td>
</tr>
<tr>
<td>Power</td>
<td>Si solar cells for 1.1 W</td>
</tr>
<tr>
<td>Camera</td>
<td>640 x 480 CMOS</td>
</tr>
<tr>
<td>Expected life time</td>
<td>??</td>
</tr>
</tbody>
</table>

Captured Earth Images are Distribution to Mobile Phones
XI-IV is still perfectly working after 13 years in orbit

Recently Downlinked Photos
**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

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

**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

- Attitude stabilization
  - 0.8 arcsec / 8.8s

- Temperature stability
  - 50°C, ±0.1°C

- 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

1 x 10^-3 rad / s  1 x 10^-5 rad / s  1 x 10^-7 rad / s

Coarse attitude control (Gyro, Magnetic Sensor, MTQ)

Parameter phase (STT, FOG, RW)

Precise attitude control phase (STT, FOG, RW)

Observation phase (Telescope, RW)

Mission requirement 4 x 10^-7 rad / s
Sever Thermal Stability is Achieved by:

Occasionally

Temperature stability < 0.1°C
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.

Late 2017 or early 2018
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)

Development Process

- Four satellite development
- Novel Missions Demo.

Infrastructure

- Low cost, Quick, Practical level
- Human Resource Training
- Ground Station
- Ground Testing
- [Standardization]
- Personal use
- Novel missions
- Foreign Customers
- New utilities
- New Players

Satellites, components, infrastructure with high competitiveness

- “Hodoyoshi”(good enough) reliability

Low cost supply chain network

Miniature components

Advanced components

Optical system, Image processing

Mission creation

Space science mission

New Paradigm of Space Development and Utilization

Tech. Demonstration

Space science mission

New utilizations

New Players
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)
“Rental Space” in Hodoyoshi 3 & 4

- 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.

Provided Services:
- Electric power
- Information line
- Camera
- Windows
Inside of 10cm Cubic Space

This message can be uplinked

“Moving Earth” as seen through the window

20 second video clip is downlinked and sent to Sanrio
HODOYOSHI-2 (RISESAT)

International Space Science Platform

- High Precision Telescope - HPT (Taiwan/Vietnam)
- Meteor counter - DOTCam (Taiwan (NCKU))
- Ocean Observation Camera - OOC (Tohoku University)

Camera Instruments

- SDTM - MEMS Magnetometer (Sweden)
- TIMEPIX - Particle counter (Czech)
- TriTel – 3D Dosimeter (Hungary)

Size:
- 50cm
- 55kg

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

Power:
- 100W

ACS:
- <0.1°

Rocket:
- Epsilon

2018 launch
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

Flyby velocity > a few km/s
LOS (Line of sight) control
Close flyby (altitude: ~30km)

High resolution asteroid observation enabled by onboard image feedback control of scan mirror
Earth photos captured from deep space by PROCYON

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
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 “JAPAN BOOTH” at West Colony.
  – 21 Japanese companies and universities join.

• The Portal Website (Makesat.com) has just been released.
  – https://makesat.com