ISSL
Intelligent Space Systems Laboratory
The University of Tokyo

9
Satellites Launched

5
Satellites will be launched soon

16
Years of In-orbit Satellite Operations

104
Students Graduated

In operation (16 years)

XI-V (2005)
In operation (14 years)

PRISM (2009)
In operation (10 years)

Nano-JASMINE
Awaiting launch
Collaborator: NAOJ

HODOYOSHI 1, 3, 4 (2014)
In operation (5 years)
Collaborator: Axelspace, NESTRA

TRICOM-1R (2018)
End of operation (0.5 years)
Collaborator: JAXA

AQT-D
Will be launched in 2019
Collaborator: UT-SPL

RWASAT-1
Will be launched in 2019
Collaborator: Rwanda

G-Satellite
Will be launched in 2020
Collaborator: TOCOGS, JAXA

EQUULEUS
In development
Collaborator: JAXA

MicroDragon (2019)
In operation (0.5 years)
Collaborator: VNSC

PROCION (2014)
End of operation (3 years)
Collaborator: JAXA
The First Interplanetary Full-scale Micro-Spacecraft

PROCYON
Earth from 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

Observed Earth’s corona
(Kameda, et al., Geophysical Research Letters, 2017)

67P/Churyumov–Gerasimenko
EQUULEUS
To be The first CubeSat to Lunar Lagrange point

(EQUULEUS = EQUilibriUm Lunar-Earth point 6U Spacecraft)
EXPLORATION MISSION-1: LAUNCHING
SCIENCE & TECHNOLOGY
SECONDARY PAYLOADS

1. PRIMARY MISSION
   TESTING SLS AND ORION
   SPACE LAUNCH SYSTEM (SLS)
   LIFTS MORE THAN ANY EXISTING LAUNCH VEHICLE

2. ORION STAGE ADAPTER
   SUPPORTS BOTH PRIMARY MISSION AND SECONDARY PAYLOADS

3. ORION SPACECRAFT
   TRAVELING THOUSANDS OF MILES BEYOND THE MOON, WHERE NO CREW VEHICLE HAS GONE BEFORE

4. SECONDARY PAYLOADS
   THE RING THAT WILL CONNECT THE ORION SPACECRAFT TO NASA'S SLS ALSO HAS ROOM FOR 13 HITCHHIKER PAYLOADS

5. 13 CUBESAT EXPLORERS
   GOING TO DEEP SPACE WHERE FEW CUBESATS HAVE EVER GONE BEFORE.

6. SHOEBOX SIZE
   PAYLOADS EXPAND OUR KNOWLEDGE FOR THE JOURNEY TO MARS

7. AVIONICS
   (SELF-CONTAINED AND INDEPENDENT FROM THE PRIMARY MISSION) SEND CUBESATS ON THEIR WAY
### Spec. of EQUULEUS

<table>
<thead>
<tr>
<th>Section</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanical &amp; Structure</strong></td>
<td>• 6U, with two wings of SAPs (with gimbaling)</td>
</tr>
<tr>
<td></td>
<td>• &lt; 11 kg (wet)</td>
</tr>
<tr>
<td><strong>Propulsion</strong></td>
<td>• 1mN x 4, 4mN x 2 Water Resist Jet, 70sec Isp</td>
</tr>
<tr>
<td></td>
<td>• 1.2kg H₂O, 80m/s DV</td>
</tr>
<tr>
<td><strong>Avionics</strong></td>
<td>• 1 On Board Computer</td>
</tr>
<tr>
<td></td>
<td>• 1 Thruster Control Board</td>
</tr>
<tr>
<td><strong>Elec Power</strong></td>
<td>• 50W(1AU, BOL) (MMA)</td>
</tr>
<tr>
<td></td>
<td>• Li-ion BAT, 34.5 Wh</td>
</tr>
<tr>
<td><strong>Telecom</strong></td>
<td>• X-band MGA(D/L) x 1</td>
</tr>
<tr>
<td></td>
<td>• X-band LGA(D/L) x 5</td>
</tr>
<tr>
<td></td>
<td>• X-band LGA (U/L) x 2</td>
</tr>
<tr>
<td></td>
<td>• Chip Scale Atomic Clock</td>
</tr>
<tr>
<td><strong>Attitude Control</strong></td>
<td>• XACT-50 (BCT)</td>
</tr>
<tr>
<td><strong>Payload</strong></td>
<td>• Extreme Ultra Violet Plasma Imager (PHOENIX)</td>
</tr>
<tr>
<td></td>
<td>• Lunar Impact Flash Camera (DELPHINUS)</td>
</tr>
<tr>
<td></td>
<td>• Dust Detector (CLOTH)</td>
</tr>
</tbody>
</table>

![Satellite Image](image-url)
Missions of EQUULEUS

- [Engineering] **primary mission**
  demonstration of the trajectory control techniques within the Sun-Earth-Moon region

- [Science #1] **PHOENIX**
  Imaging observation of the Earth’s plasmasphere

- [Science #2] **DELPHINUS**
  Lunar impact flashes observation

- [Science #3] **CLOTH**
  Smart MLI to detect micro dust in the cis-lunar region

*Constellation images are from [http://www.seasky.org/sky.html](http://www.seasky.org/sky.html)*
Science Payload #1
PHOENIX
Extreme Ultra Violet Plasma Imager
PHOENIX
(Plasmaspheric Helium ion Observation by Enhanced New Imager in eXtreme ultraviolet)

- Observe **Large structure of He+** in the Earth’s plasmasphere
  - understanding of the physical process governing the terrestrial plasmas of the Earth

- **Structure of plasmas surrounding the Earth** with respect to the Earth's magnetic field
  - understanding of the escape process of the Earth's atmosphere from the polar region
  - understanding of the evolution of the atmosphere of the Earth and Earth-like planets
Key Point of Design

- Optical Design
  - Optimized for He+(30.4nm) observation
  - Three-stage microchannel plates (MCP) detector
- Mechanical Shutter
  - To protect the thin filter from the Sun
- Requirement to Attitude Stability
  - 0.08 deg @ 10 mins (3σ)

<table>
<thead>
<tr>
<th>Content</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Mass and size of telescope</td>
<td>0.48 kg / 70 × 70 × 100 mm</td>
</tr>
<tr>
<td>Power</td>
<td>1.8 W (maximum)</td>
</tr>
<tr>
<td>Field of view</td>
<td>11.9×11.9 deg</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>0.085 deg (0.1 Re from the moon orbit)</td>
</tr>
<tr>
<td>Count rate</td>
<td>3 count/min/pix/Rayleigh</td>
</tr>
</tbody>
</table>
Development and Test of FM

FM Development & Testing Status
- Optical Performance Test
- Unit Thermal Cycle Test
- Unit Thermal Vacuum Test
  - 100 times open/close test of the Mechanical Shutter
- Unit Vibration Test

All Unit Test has been completed!

FM of PHOENIX Telescope

FM of PHOENIX Electronics

Result of Optical Performance Test
Science Payload #2
DELPHINUS
Lunar Impact Flash Camera
DELPHINUS
(DEtection camera for Lunar impact PHenomena IN 6U Spacecraft)

• Lunar impact flashes
  – The flash of light emitted by the high-velocity meteoroids which impact on the moon surface
  – The first mission to observe LIFs generated in far side of the moon
  – contribute to risk evaluation for future human activities and infrastructures on the lunar surface

• Near-Earth Asteroids (NEOs)
Key Point of Design

- **Onboard LIF Detection & Extraction**
  - Real time Detection 4.5-Vmag faint LIFs from 60-fps movie with noises

- **Curse of pixel number**
  - If the probability of mis-detection for 1 pixel = 0.01%
  - Mis-detection of 1frame: 0.0001*659*494 = 33
  - Mis-detection rate 33*60 = 2000 detection/s !

- **Detection Algorithm**
  - Using PSF information of LIFs which is completely different from noises
  - Finally, scientists will evaluate using two extracted images from two cameras

## Content Value

<table>
<thead>
<tr>
<th>Content</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass and size of telescope</td>
<td>0.57kg / 100 × 100 × 50mm</td>
</tr>
<tr>
<td>Power</td>
<td>4.0 W (maximum)</td>
</tr>
<tr>
<td>Pixel number and size</td>
<td>659 × 494 / 7.4 × 7.4 um</td>
</tr>
<tr>
<td>Wavelength</td>
<td>400 nm – 800 nm</td>
</tr>
<tr>
<td>Lens</td>
<td>f = 500 mm, F1.4</td>
</tr>
<tr>
<td>Frame Rate</td>
<td>60 fps (maximum)</td>
</tr>
<tr>
<td>Detectable magnitude</td>
<td>4.5 Vmag (S/N=2)</td>
</tr>
</tbody>
</table>
Development and Test of FM

FM Development & Testing Status

☐ Optical Performance Test
  ☑ Flat image, Dark image, Real sky
☐ Unit Thermal Cycle Test
☐ Unit Thermal Vacuum Test
☐ Hardware Test of LIF Detection

All Unit Test has been completed!
FM Hardware Test of LIF Detection

Camera 1

Previous frame

LIF detection

Next frame

Camera 2

time
Science Payload #3
CLOTH
Dust Detector integrated with MLI
CLOTH
(Cis-Lunar Object detector in Thermal Insulation)

- **Measurement of dust environment in the cis-lunar region** by PVDF* film sensors installed inside MLI
- **Scientific objective**
  - provide the first insight of spatial distribution of sub-mm solid objects in the cis-lunar space
- **Technological demonstration**
  - “Smart” MLI for micro-meteoroid impact detection
  - It can be also used for Debris detection around the Earth

*PVDF: Poly-Vinylidene DiFluoride

One smart MLI: Effective Area $< 450\text{cm}^2$

If every satellites carry the Smart MLI...
Total Effective Area is increasing!
Key Point of Design

- **Layer Design**
  - PVDF films are integrated with Multi-layered Insulation

- **Thermal Property**
  - the effective absorption
  - the effective emissivity
    \[ \alpha < 0.05, \quad \varepsilon < 0.05 \]

- **Onboard Dust Detection**
  - Electric Circuit detection system
    - pre-amplifiers, band-pass filters, rectifiers, and integrators

- **Grounding design to decrease EMC noise**

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### Table: Design Specifications

<table>
<thead>
<tr>
<th>Content</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total mass of sensors</td>
<td>0.03kg</td>
</tr>
<tr>
<td>Power</td>
<td>1.0 W (maximum)</td>
</tr>
<tr>
<td>Total sensitive area</td>
<td>439cm²</td>
</tr>
<tr>
<td>Detectable dust size</td>
<td>&gt; 4μm at &gt; 10 km/s</td>
</tr>
<tr>
<td>Effective Absorption</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Effective Emissivity</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>
Development and Test of FM

FM Development & Testing Status
✓ Hypervelocity Impact Test
✓ Unit Thermal Cycle Test
✓ Unit Thermal Vacuum Test
✓ Unit Vibration Test
• Integrated Rapid Decompression Test

All Unit Test has been completed!
Development Status of EQUULEUS
Development status

✓ Mission approval by JAXA: April 2016 (detailed design)
✓ PDR (internal) : August - September 2016 (EM AI&T)
✓ CDR#1: July 2017
✓ CDR#2: June 2018
✓ FM Integration
✓ Thermal Cycle Test: February 2019 Passed!
✓ Thermal Vacuum Test: May 2019 Passed!
✓ Water Propulsion Driving Test Now Testing in Japan
  • Vibration Test: November 2019
  • Pre-shipment review: Spring 2020
  • Launch: November 2020
FM Integration & Testing

FM Integrated Thermal Cycle Test

FM Integrated Propulsion Test

FM Integrated Thermal Vacuum Test
Conclusion
Conclusion

• **EQUULEUS**
  – Lunar Explorer Probe developed by UT and JAXA
  – three science payloads

• **PHOENIX**
  – Imaging observation of the *Earth’s plasmasphere*

• **DELPHINUS**
  – *Lunar impact flashes* observation

• **CLOTH**
  – **Smart MLI** to detect micro dust in the cis-lunar region

• Unit tests of the science payloads were **completed**.
• We integrated FM and conduct integrated tests.
Why don’t you visit our exhibition booth?

University Booth U11

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Prof. Funase  Dr. Ikari