Hayabusa-2:
A Carbonaceous Asteroid Sample Return Mission

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California Institute of Technology, Pasadena, CA, USA

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   Japan Aerospace Exploration Agency (JAXA)
The Structure Model of Hayabusa-2 S/C during the Initial Integration Test in December, 2012
Hayabusa Family:
Sample Returns from NEOs and Beyond

Hayabusa
Itokawa = S type
(2003-10)

Hayabusa-2
1999 JU3 = C type
Lessons Learned from Hayabusa
(2014-20)

Post Hayabusa Era

Solar Power Sail
D type Jupiter Trojan
Hayabusa + IKAROS
Technology (Early 2020’s)

And Beyond

OSIRIS-REx
1999 RQ36 = B type
New Frontier Class
(2016-23)

Carbonaceous Chondrites

CP-IDP,
Ultra-carbonaceo
us AMMs,
Tagish Lake?

Marco Polo-R
2008 EV5 = C type
Cosmic Vision-M
(2022-27)

Ordinary Chondrites

Main Asteroid Belt

S type

C type

D type
Hayabusa-2 in 2014-20: A Carbonaceous Asteroid Sample Return

<Major Characteristics>
• The first rendezvous and sample return of a C-type asteroid (1999 JU3)
• The spacecraft system design has a direct heritage and lessons from Hayabusa-1 with an impactor

<Scientific Objectives>
(1) Material distribution map at the Main Asteroid Belt
(2) Chemical evolution of water and organic material (Life precursors)
(3) Internal structure and evolution process of highly porous primitive bodies
Spacecraft Comparison: Hayabusa vs Hayabusa-2

**Hayabusa**
- Size: 1m × 1.6m × 1.1m (body)
- Mass: 510kg (Wet)

**Hayabusa2**
- Size: 1m × 1.6m × 1.25m (body)
- Mass: 600kg (Wet)

① Communication: X-band + Ka-band
② Ion engine: modified
③ Small lander: MASCOT (Mobile Asteroid Surface Scout) from DLR
④ AOCS: 4 reaction wheels
Target Asteroid: 1999 JU3

Rotation period: 0.3178 days (~7.6 h)

\((\lambda, \beta) = (331, 20), (73, -62)\)

Kawakami Model    Mueller Model

Axis ratio = 1.3 : 1.1 : 1.0

Size: 0.87 ± 0.03 km

Albedo: 0.070 ± 0.006

H = 18.82 ± 0.021, G = 0.110 ± 0.007

Type: Cg

Shape model by Kawakami

Orbit

Itokawa

(by Mueller et. al)
Near Earth Objects: Itokawa vs. 1999 JU3 at a Glance

(162723) 1999 JU3  
(C)

~980 m

(25143) Itokawa  
(S)

Mars

Earth

Earth Crossing Orbits

International Space Station

(Collage Courtesy: P. Lee, 2006)

(Model Courtesy: Kaasalainen, et al., 2008)
### Hayabusa-2 Mission Profile

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<td>month</td>
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<td>06</td>
<td>12</td>
<td>06</td>
<td>08</td>
<td>12</td>
<td>12</td>
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</table>

**Launch windows**

**Earth Swing-by**

**IES operation**

- Arrival at 1999JU3
- Science observation, Sampling
- Departure from 1999JU3
- Earth return

**Spacecraft**

**Impactor**

**New Experiment**
Ion Thruster Assembly (ITA)

Thruster 4 units including 1 stand-by
3 units simultaneous operation
System thrust 5 - 30 mN
System Power 250 – 1,200 W
Specific Imp. 2,600 – 3,000 sec
Ion Prod. Cost < 250 eV
Lifetime > 18,000 hours
Gimbal +/-5 deg
Xe Loading < 73 kg
Dry Mass < 70 kg
# Engineering/Science Payloads

<table>
<thead>
<tr>
<th>Payloads</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Multiband Imager (ONC-T)</strong></td>
<td>Wavelength: 0.4 – 1.0 μm, FOV: 5.7 deg x 5.7 deg, Pixel Number: 1024 x 1024 px&lt;br&gt;filter (ul, b, v, w, x, p, Wide) (Heritage of Hayabusa)</td>
</tr>
<tr>
<td><strong>Near IR Spectrometer (NIRS3)</strong></td>
<td>Wavelength: 1.8 – 3.2 μm, FOV: 0.1 deg x 0.1 deg&lt;br&gt;(Heritage of Hayabusa, but 3μm range is new)</td>
</tr>
<tr>
<td><strong>Thermal IR Imager (TIR)</strong></td>
<td>Wavelength: 8 – 12 μm, FOV: 12 deg x 16 deg, Pixel Number: 320 x 240 px&lt;br&gt;(Heritage of Akatsuki)</td>
</tr>
<tr>
<td><strong>Laser Altimeter (LIDAR)</strong></td>
<td>Measurement Range: 30 m – 25 km (Heritage of Hayabusa)</td>
</tr>
<tr>
<td><strong>Sampler</strong></td>
<td>Minor modifications from Hayabusa-1&lt;br&gt;(Heritage of Hayabusa)</td>
</tr>
<tr>
<td><strong>Small Carry-on Impactor (SCI)</strong></td>
<td>Small system released form the spacecraft to form an artificial crater on the surface (New)</td>
</tr>
<tr>
<td><strong>Separation Camera (DCAM)</strong></td>
<td>Small, detached camera to watch operation of Small Carry-on Impactor&lt;br&gt;(Heritage of IKAROS)</td>
</tr>
<tr>
<td><strong>Small Rover s (MINERVA II-1, II-2)</strong></td>
<td>Similar to MINERVA of Hayabusa-1&lt;br&gt;(possible payload: Cameras, thermometers)&lt;br&gt;(Heritage of Hayabusa)</td>
</tr>
<tr>
<td><strong>Small Rover (MASCOT)</strong></td>
<td>Supplied from DLR &amp; CNES&lt;br&gt;MicrOmega, MAG, CAM, MARA</td>
</tr>
</tbody>
</table>
Small Carry-on Impactor (SCI): A New Challenge to Investigate Fresh Sub-surface Materials

- ① high speed debris
- ② high speed ejecta
- ③ low speed ejecta

1999 JU3

Impactor

Separation mechanism

explosion

separation

①, ②, ③
½ Scale EFP Impact Test on the Ground

explosion

trajectory

impact!
Orbital Determination

Ambiguity of 1σ on July 29, 2005

<table>
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<tr>
<th>Method</th>
<th>Position (km)</th>
<th>Velocity (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R&amp;RR</td>
<td>1,800</td>
<td>72</td>
</tr>
<tr>
<td>Optical</td>
<td>45</td>
<td>6</td>
</tr>
</tbody>
</table>

Image of Itokawa taken by STT

GNC Lessons Learned from Hayabusa-1 (1/3):
Optical Navigation Approach in Heliocentric Frame
GNC Lessons Learned from Hayabusa-1 (2/3): Landmark Navigation in Proximity Operation

* Relative position determination against the asteroid
  • Terrain contour matching guidance comparing with actual images with CGs

Far Field <= Outline of the Asteroid
Near Field  <= Geographical Features
GNC Lessons Learned from Hayabusa-1 (3/3): Autonomous Landing in Microgravity Condition

Descent Sequence

Actual Images during the Descent
International Cooperation in Progress

To NASA
- US scientists participation
- Asteroid sample provision
- Accommodation of appointed personnel on mission ops.

To JAXA
- Deep Space Network support
- Radiometric navigation support
- Cooperation with OSIRIS-REx

* NASA/JAXA LOA on potential collaboration between the Hayabusa-2 and OSIRIS-REx missions was signed on Nov. 9, 2012
DLR/CNES Contribution: MASCOT
(See Jaumann, et al. for more details)

- “Mobile Asteroid Surface SCOuT” is a dedicated landing package for in-situ science on small body surfaces, as a part of the Hayabusa-2 payloads
- Completely autonomous on-asteroid operation with uprighting and relocation capability
- Mass: 10 kg
- Payloads: Magnetometer, Radiometer, Wide-Angle-Camera, MicroOmega
- One MASCOT system engineer serves as a residential liaison at the Sagamihara campus of JAXA since the initial integration test in 2013.

(Courtesy: C. Grimm, DLR Bremen)
Worldwide Outreach Campaign in Progress

With the "Hayabusa2"
Let's go to asteroid 1999 JU₃ and return to Earth.

Send your name and a message on Hayabusa2 !
~ Let's meet with Le Petit Prince! Million Campaign 2 ~

[Campaign Deadline]
12:00 p.m. (Noon) on July 16 (Tue.), 2013 (JST)
For more details about how to apply, please see the reverse side.

The Hayabusa2, which is scheduled to be launched in 2014, will carry your name and heartfelt message as it travels to space for about six years. Why don’t you join our challenging project to space?

Step 1 ~ Check where and how your name/message will be on Hayabusa2 ~

Load location 
Target marker
Your names
Load contents

Step 2 ~ Check your preferred 'location and message type' ~

message type

<table>
<thead>
<tr>
<th>Name</th>
<th>Limit of letters; per names, one name shall consist of 20 alphabetic letters or less including spaces between words.</th>
</tr>
</thead>
<tbody>
<tr>
<td>[A]Name</td>
<td>Limit of letters (Same as above)</td>
</tr>
</tbody>
</table>
| [B]Name and Message | Limit of letters:
  * For names, one name shall consist of 20 alphabetic letters or less including spaces between words.
  * One message shall consist of 60 alphabetic letters or less including spaces between words. |
| [C]Collection of messages/illustration | Nothing larger than 8 1/2” x 11” size paper |

Step 3 ~ Web registration~

http://www.planetary.org/get-involved/messages/hayabusa2-2/

Special Thanks
The Planetary Society in USA is cooperating with our campaign and has opened web application form in English. We greatly appreciate their kind support.
Final Remarks

• Hayabusa-2 has just completed the initial integration test of its FM in May 2013. The final integration test will start this fall.

* Mission profile of Hayabusa-2:
  > Launch on Dec. 2014
  > Proximity Operation from June 2018 to Dec. 2019
  > Earth Return on Dec. 2020

• Both lessons learned from Hayabusa and Hayabusa-2 experiences can potentially contribute to a human NEA mission success such as:
  > Optical navigation approach to asteroid from heliocentric space
  > Landmark navigation in proximity operation around an asteroid
  > Autonomous landing in microgravity condition
  > Redundancy against malfunctions in a long flight operation
  > Scientific knowledge on S-type and C-type NEOs

• International collaborations are in progress
• Worldwide outreach effort is also in progress