Return of the Falcon

The story of "Hayabusa", a spacecraft to explore an asteroid

Second Edition

祈 り

小惑星探査機 はやぶさ の物語

■World of asteroid

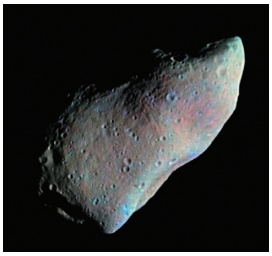
Speaking of an asteroid, what does that bring to your mind? A tiny celestial body, a celestial body like stone, the Little Prince's home?

Since an asteroid could only be seen as a tiny dot, even if we observed it through a large telescope from the earth, we didn't know its shape until only a short while ago. However, since the early 1990s, because spacecraft became able to get close to asteroids, we have gradually come to know the real nature of asteroids.

All asteroids, whose images were taken by spacecraft in the past, have a form far from being round in shape with many craters that can be seen on the surface. On implicit recognition, it was believed that an asteroid was probably such a thing. The "Hayabusa" squashed this implicit recognition.

About how many asteroids are there? In fact, the total number is yet unknown because we are in the stage where new asteroids are being discovered one after another. At the beginning of 2007, there were 350,000 asteroids whose orbits were confirmed. Itokawa is one of them. However, it is a small asteroid whose size is only about 500m.

Asteroids are considered to be celestial bodies, which maintain information of the solar systems birth and its subsequent evolution. By understanding Itokawa, we may be able to see remote events in the solar system.



Gaspra

Ida and its satellite Dactyl

Mathilde

Eros

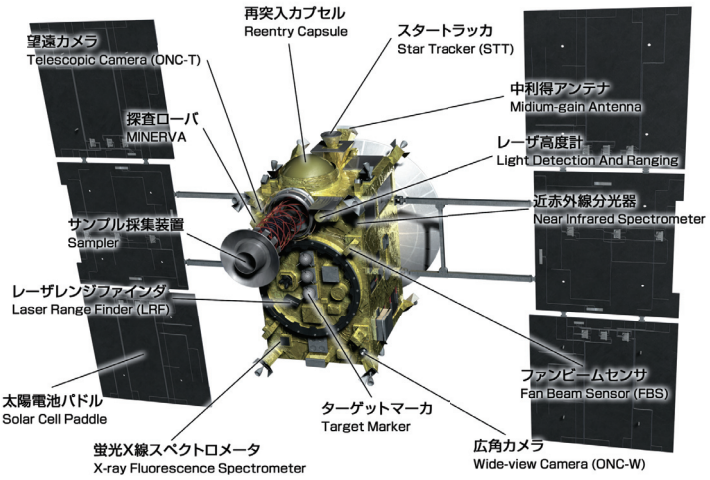
The asteroids which spacecraft visited before: Gaspra is 20km in size, 40km for Eros, about 60km for Ida and Mathilde, and those are quite big compared to Itokawa. Dactyl, a satellite of Ida, is 1.6km in size. (The images are from NASA/JPL)

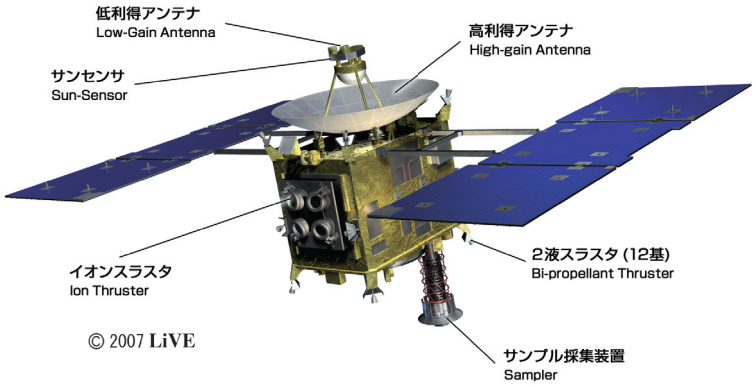
Asteroid Itokawa

The asteroid Itokawa was discovered by LINEAR (Lincoln Near-Earth Asteroid Research) project in the US on September 26, 1998. It is a typical near-earth asteroid, which intersects the orbit of the earth. At first, it was called 1998 SF36 as a tentative name (provisional designation), but it was actively observed because it became an intended asteroid to explore. Thus, its orbit was soon determined accurately, and the number 25143 was given in June 2001. Since an asteroid can have a name once it gets a number, the Institute of Space and Astronautical Science (ISAS) of that time asked the LINEAR project to name it Itokawa, and it was accepted. Eventually, the name of Itokawa was officially granted by the International Astronomical Union (IAU). Needless to say, it was named after the late Dr. Hideo Itokawa, the father of the Japanese rocketry. It was in 1955 when Dr. Itokawa carried out the first test launch of the Pencil Rocket. Exactly 50 years later, Hayabusa launched by the M-V-5 rocket reached the asteroid Itokawa.

■“HAYABUSA” spacecraft

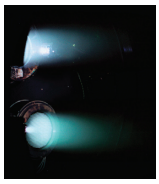
The Hayabusa spacecraft carries various high-tech equipment in its small body. Even with its solar paddles open it is only 5m in size. The body is box shaped whose width is about 1m, and weighs only about 500kg. Such a tiny thing can travel as far as several billion kilometers. Naturally, once it departs, people cannot go to repair it even if there is some trouble. It has only itself and the radio signal from the earth to rely on.





Ion engine

It controls the orbit of spacecraft by jetting out plasma of xenon at high speeds. Large acceleration can be obtained with a light mass because the electric power generated by the solar cells becomes an energy source.

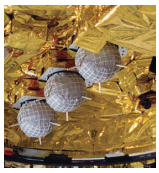


Sampler hone

At the moment of touching the surface of the asteroid, a bullet is ejected in the hone and it crushes the surface of the asteroid. The smashed fragments rise in the hone and are stored in the case of the spacecraft. The time during which it touches the surface is only several seconds. energy source.

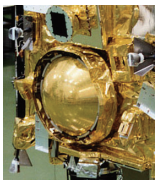
Target marker

It is released before landing and becomes a mark on the asteroid surface. When a flash bulb installed in the spacecraft is ignited, the camera on the spacecraft takes images of the white glisten reflected from the marker, thus helping the spacecraft recognize its own location.



Capsule

The case containing surface materials is conveyed into a capsule and the lid is shut. When the spacecraft returns to the earth, the capsule will be separated, reenter the atmosphere, and eventually the capsule will parachute down to the earth.



■Big voyage

●May 9, 2003 : Launch

Hayabusa is a small asteroid explorer, originally called MUSES-C. It was launched by the M-V-5 rocket from the Uchinoura Space Center in Kagoshima Prefecture at 13:29:25 on May 9, 2003. It was a successful launch, and the MUSES-C spacecraft was renamed Hayabusa (falcon in English). Hayabusa began a journey to the vast outer space.

After the launch, while it was working hurriedly, such as deploying solar paddles and extending the sampler hone, Hayabusa was swiftly moving out from the earth. Moreover, it also lit off the newly developed ion engines and gradually changed its orbit. However, the orbit of Hayabusa in the first year looked almost the same as the one of the earth. Yet, Hayabusa was accumulating energy into the orbit by firing its ion engines during the first one year.

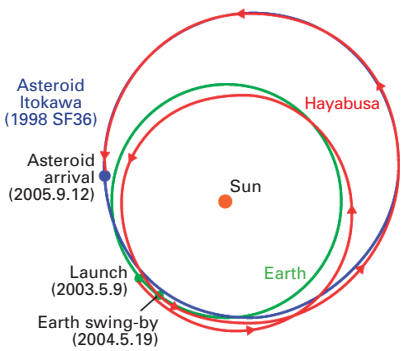
Hayabusa has four ion engines. One of them is a backup. Since the power generated by the solar cells is different depending on the distance from sun, the ion engines work in the one to three ranges according to the level of power generation.

Born of Hayabusa

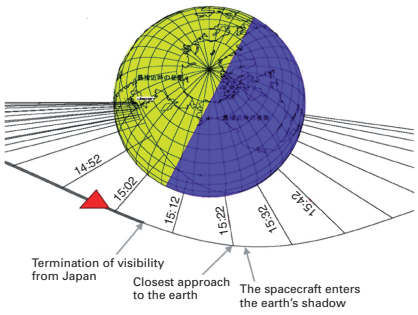
●May 19, 2004 : Earth swing-by

About one year after the launch, Hayabusa returned to the earth on May 19, 2004. This is because of the earth's swing-by for orbit control by using the earth's gravity. At 15:21:42 (Japan time), Hayabusa approached an altitude of about 3,700km over the Pacific Ocean. It passed through a place only about 1km away from the scheduled point. At this time, the orbit was obviously changed due to accumulated energy in the orbit by ion engines. It altered into the orbit similar to that of the asteroid Itokawa.

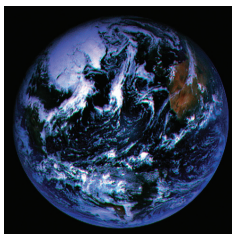
The orbit from launch to arrival at the asteroid

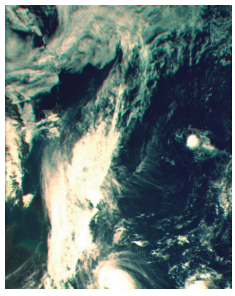


Orbit during earth swing-by



The earth image taken during the earth swing-by

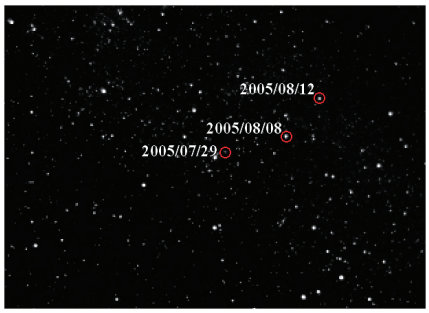




●July 29, 2005 : We could see Itokawa

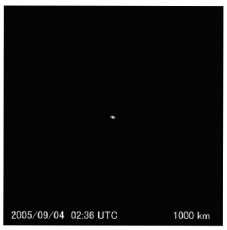
After the earth swing-by, the ion engines continuously worked. Then, in July 2005, Hayabusa went into the state of “conjunction,” which means that Hayabusa located behind the sun when it was seen from the earth. During conjunction, we could not communicate with the spacecraft due to interference by the sun. Therefore, we stopped the ion engines and waited until we were able to communicate again.

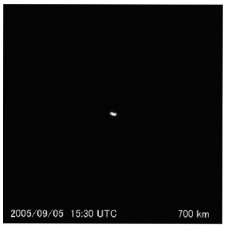
On July 29, 2005, the long-awaited moment came. Hayabusa finally succeeded in taking an image of Itokawa. However, due to constraint on the attitude of the spacecraft at that time, it was not by a camera for taking asteroids, but it was by Star Tracker that determined the attitude of the spacecraft. The images of Itokawa were also taken in August, and the accurate position of the spacecraft relative to Itokawa was acquired. Hayabusa was flying almost in the exact orbit which was planned.

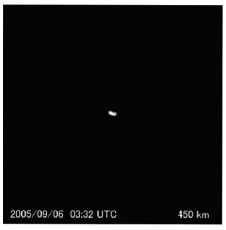


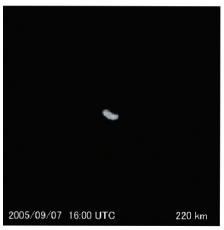
Left Itokawa taken by Star Tracker. Using the positions of Itokawa seen from the spacecraft, the accurate orbit of the spacecraft was determined.

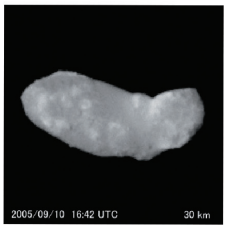
Right Photos when approaching Itokawa. From September 4, 2005 (1,000km distance) to September 10, 2005 (30km distance). The images are about one arc degree square.











●September 12, 2005 : Arrived at Itokawa

We stopped the ion engines on August 28, 2005, which had been running most of the time since the launch. The ion engines accomplished the role of the outward voyage. The total working hours of the ion engines were about 25,800 hours.

The distance to Itokawa was down to 3,500km at the end of August. In September, the image of Itokawa, which had been only a point till then, was getting larger by the day. The shape was gradually becoming clearer. It had an elongated shape as expected. The fact that it rotated with the period of about 12 hours was also confirmed.

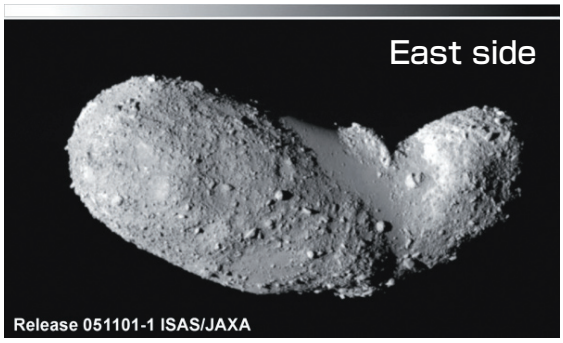
Moreover, on September 12, 2005, Hayabusa hovered in the place of about 20km from the asteroid Itokawa. Finally it arrived. Everybody was surprised with the image of Itokawa sent by Hayabusa at that time. The surface was completely not what we expected. There were no craters on the surface. Instead, the surface was covered with a lot of rocks.

■Mysterious world of Itokawa

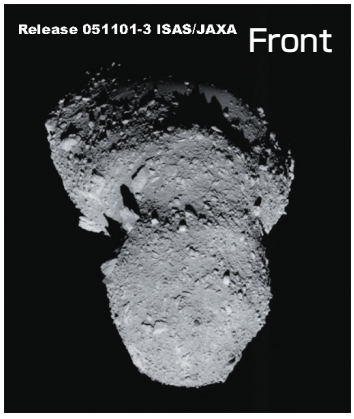
During the first three weeks after reaching Itokawa, the spacecraft was flying a distance between 20km and 10km from Itokawa. Moreover, in October, it was brought close to about 7km from Itokawa, and it was brought closer to a place of about 4km at the end of October. During this period, using the full capability of the observation equipment carried on the Hayabusa, the mission team acquired detailed data about Itokawa.

The most significant feature of Itokawa is that the surface is covered by various sizes of the plentiful rocks. Those rocks are called “boulders” The biggest boulder is the one called “Yoshinodai” named by the mission team, and its width is 50m and its height is 20m. In addition, there is another boulder called “Pencil” which is sharply peaked.

Crater familiar to asteroids is not conspicuous. However, when investigated in detail, it turned out that there are about 40 craters. When looking at the photo of Itokawa, we can see that a part of the surface is relatively flat. A feature of Itokawa is that two kinds of surfaces, the rough surface and the smooth surface, are clearly divided. Moreover, the shape is elongated as expected, but it looks as if two objects are attached. At first glance, it has a shape like a sea otter, doesn’t it? These facts serve as an important clue when solving the birth of Itokawa.



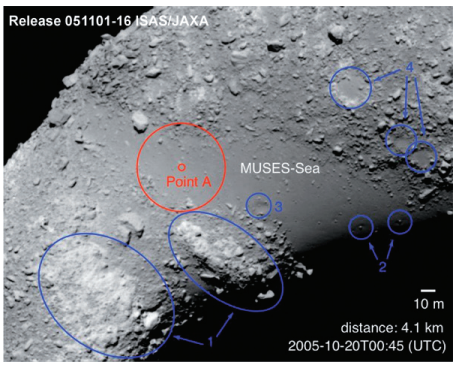
Itokawa sea otter



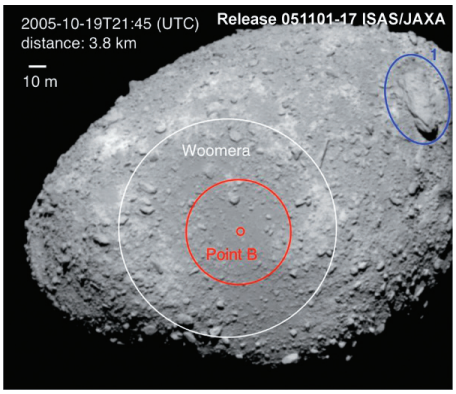
The images of the whole asteroid Itokawa taken by Hayabusa. The image from the east side looks just like a sea otter. The lump of the rock, which is projected on right-hand side in the west side image, is Yoshinodai. Moreover, the rock, which is projected on the left of the center (around the neck of a sea otter), is a Pencil. In the front image, there is a blackish color of boulder in the center of the head part of the sea otter. This is called Black Boulder, and it has become the origin of the longitude.

The biggest concern about the mission was where the spacecraft would touchdown (land). Since the surface of Itokawa was unexpectedly rugged, the places where it can land were very limited. One of the candidates was the place marked Point A. Here was a flat place that was located exactly at the neck of the "sea otter" and the mission team calls it "Muses Sea" (the official name approved by the International Astronomical Union is "MUSES-C Regio"). Another candidate was the place marked Point B, which was at the hip of the "sea otter." The mission team called it the "Woomera desert." The Woomera desert is the name of a desert in Australia in which the capsule of the Hayabusa eventually will land (the official name has not been decided yet). Nowhere else could we find a place to touchdown other than these two sites. It might be lucky that we were able to find places where it could land.

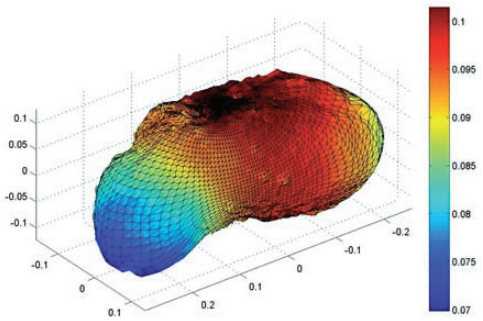
Various observations were continued during the process to make a decision of the potential site for touchdown. The Hayabusa has a multi-spectral telescopic imager (AMICA), a near-infrared spectrometer (NIRS), X-ray fluorescence spectrometer (XRS), and a laser altimeter (LIDAR) as observation equipment. As we had already mentioned, AMICA has taken a lot of images. NIRS and XRS are instruments, which investigate the spectra of infrared and X-rays, to help us know the assortment and the elemental composition of the mineral of the surface of Itokawa. LIDAR can investigate the precise gravity of Itokawa and the detailed feature of the surface by measuring an exact distance between Itokawa and Hayabusa. After those investigations, preparation of touchdown was completed.



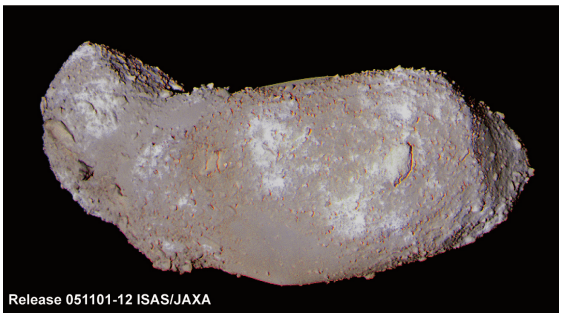
Touchdown candidate site Point A



Touchdown candidate site Point B



The precise shape, the gravity field of Itokawa, etc. were investigated by using observational data. This figure indicates the strength of gravity by color.



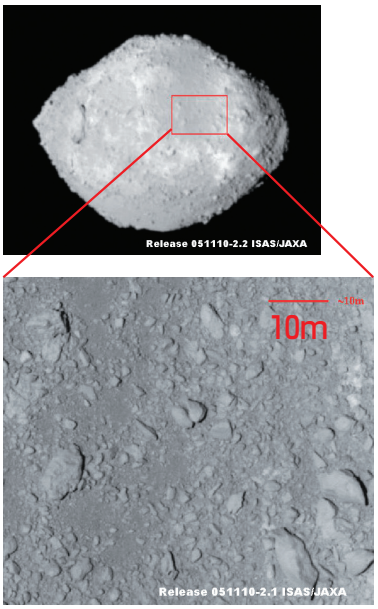
The color of the surface of Itokawa was also observed in detail. This image, although the color on the surface of Itokawa is magnified, shows that whitish parts are mixed with blackish parts.

■Touchdown (landing) rehearsal

November 2005 Hayabusa's big challenge started.

●1st rehearsal: November 4, 2005

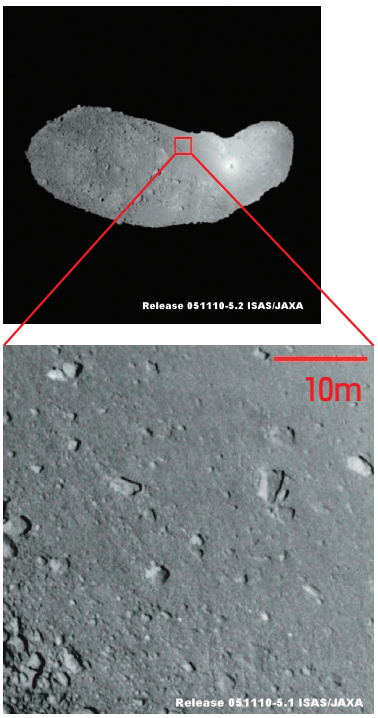
Although preparation for the landing was completed, at first the team ran through the descent test as rehearsal since it is dangerous to get down to the surface too suddenly. The purposes of this test were the calibration of the laser altimeter, confirmation of the target marker release, the image processing, and dropping of the exploration rover "MINERVA." Although Hayabusa started descending from near an altitude of 3.5km and went smoothly to about an altitude of 700m, it stopped descending due to the instructions from the earth and left the asteroid since the orbital error had become too large at that point. Although the rehearsal didn't go as well as planned, various things found out in relation to the control of the spacecraft. Also, images of the "Woomera desert" were taken. It was found that "Woomera desert" is unsuitable for touchdown since there are many boulders, which are several meters in size.



The close-up image of the Woomera desert taken at the time of the 1st rehearsal.

●Navigation guidance test: November 9, 2005

According to the test descent on November 4, the mission team knew they needed further confirmation of the navigation guidance functions for touchdown; therefore they tried to have Hayabusa approach the asteroid. The purposes were to confirm the functions of the image processing to recognize the asteroid, the auxiliary navigation from the earth, and the short-distance laser range finder, and to execute the separation test of the target marker. At this time, Hayabusa once approached to an altitude of about 70m and, after going away to about 3km, it approached to about 500m again. Moreover, the close-up image of the "Muses Sea" was also taken. Looking at the "Muses Sea" in detail, there were rocks with size of several meters. However, when compared with other regions, there were many flat parts. And when it approached to about 500m a second time, the separation test of the target marker was done. It was confirmed that the target marker had been released normally, and the photographing with a flash lamp and function of position estimation by image processing worked normally.



The close-up image of the Muses Sea taken at the time of the navigation guidance test.

●2nd rehearsal: November 12, 2005

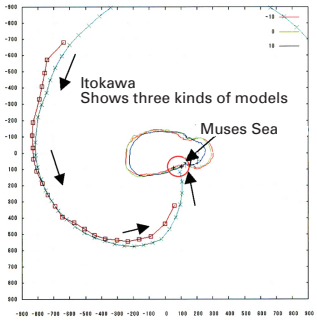
After the two descent operations above, another descent rehearsal was performed again. The purposes of this rehearsal were to confirm the navigation guidance function for touchdown, to calibrate the short-distance laser range finder, and to release the exploration rover "MINERVA." The minimum approach altitude at that time was about 55m. Regarding MINERVA, unfortunately it could not be put on the asteroid surface. In this descent rehearsal, more detailed images of the surface of Itokawa were taken.

■Touchdown

Now, it is the climax of the mission !

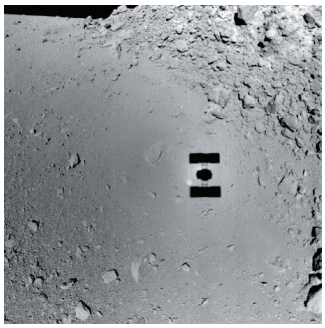
●First touchdown: November 20, 2005

The Hayabusa started descending from a point of about 1km from Itokawa at 9:00 p.m. on November 19. When it reached an altitude of 54m at 5:28 a.m. on the 20th, the mission team commanded it to release the target marker. And then the target marker was separated and descended down to the asteroid surface at the time when the spacecraft slowed down the velocity to almost zero at around an altitude of 40m. This target marker had a list of 880,000 people's names. Thus, Hayabusa was able to send the people's names to Itokawa successfully.



Hayabusa's orbit relative to Itokawa

After that, however, something strange was going on with Hayabusa. Although it should have left from the asteroid immediately after touching on the surface of the asteroid in the schedule, change in radio frequency sent by the spacecraft showed a completely different behavior. Therefore, the command was sent to Hayabusa to leave the asteroid. Afterward, when the data retrieved from Hayabusa was checked, it was found that Hayabusa had landed on the surface of the asteroid. Unfortunately, it was also confirmed that the bullet, which was supposed to be fired in order to collect the surface materials, was not discharged. However, Hayabusa became the first spacecraft ever to take off from a celestial body other than the earth and the moon.

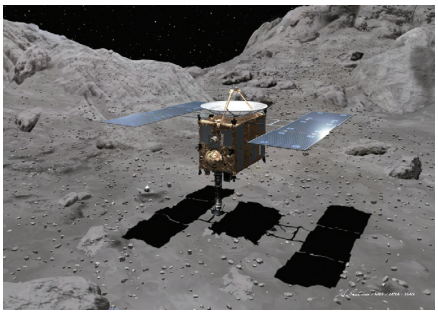


Shadow of Hayabusa itself and the target marker dropped to Itokawa.

●Second touchdown: November 26, 2005

Hayabusa started descend from an altitude of about 1km in response to command from the earth around 10:00 p.m. on November 25. It descended at almost the same place as the 1st touchdown. Since it was the same place, the target marker, which had been dropped the last time, already existed. Therefore, the target marker was not released this time.

Hayabusa was approaching the asteroid smoothly. It touched on the surface around 7:07 a.m. on the 26th, the bullet was discharged immediately, and Hayabusa took off with the sample (everyone believed so at that time.). However, the situation would take a bad turn after that.



Artistic images of touchdown of Hayabusa. At the 1st time (left), it had stayed on the Itokawa s surface for 30 minutes or more. At the 2nd time (right), touchdown was performed as planned. (Illustrated by Mr. Akihiro Ikeshita.)

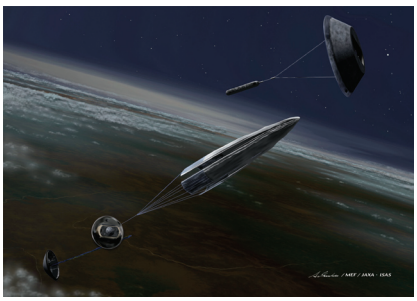
■Hayabusa after the touchdown

After the 2nd touchdown, the fuel leaked after leaving the asteroid and decelerating the ascent velocity of Hayabusa. We were unable to control the spacecraft fully although various operations such as closing the valve of the fuel pipe were tried. Furthermore, the leaked fuel might have frozen within the spacecraft. Even so, every possible means were tried to control Hayabusa. Finally, the team even tried controlling its attitude by directly jetting xenon gas, which was supposed to be used for the ion engines.

Unfortunately, the radio signal from Hayabusa was not received on and after December 9, 2005. It was thought that an abnormal attitude had happened due to a gas discharge from the fuel leakage. Furthermore, according to the investigation of the data, which remained in the spacecraft, it was regretful to find that the bullet might have not been fired at the time of the second touchdown.

Afterwards, the radio signal from Hayabusa was caught again on January 23, 2006. And then, as a result of careful operations, the orbit of spacecraft was determined successfully in March 2006. Since then, the communication with Hayabusa has been continued without interruption. Several operations were done, such as the test of the ion engines, the repair work of some broken batteries, etc. Then it succeeded in moving a sample collection container into the capsule, and shutting and sealing the lid of the capsule on January 17, 2007. The preparation for the return to the earth had finished. From February 2007, operation of the ion engines was checked again. And, from April 25, 2007, the spacecraft shifted to full cruise mode for returning to the earth.

As of May 2007, the return to the earth of Hayabusa will be scheduled for June 2010. In June 2010, the capsule will be separated when Hayabusa approaches at the midpoint of its path between the earth and the moon. The capsule will endure high temperatures due to the interaction with the atmosphere, will open a parachute to slow down, and will land in the Woomera desert in Australia.

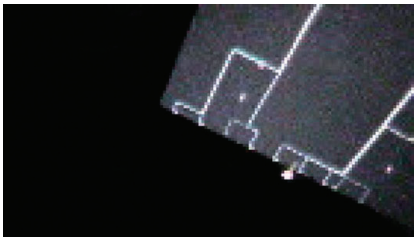


In June 2010, the capsule will separate from Hayabusa and descend to the desert in Australia at midnight. (Plan) (Illustrated by Mr. Akihiro Ikeshita.)

■Things Hayabusa left unfinished

There are two big things that Hayabusa has not done. One is that the collection of the surface material of the asteroid was not carried out as the prearranged procedure. Since Hayabusa bounded on the surface of Itokawa at the time of the 1st touchdown, we expect that the surface material must have entered into the spacecraft at that time.

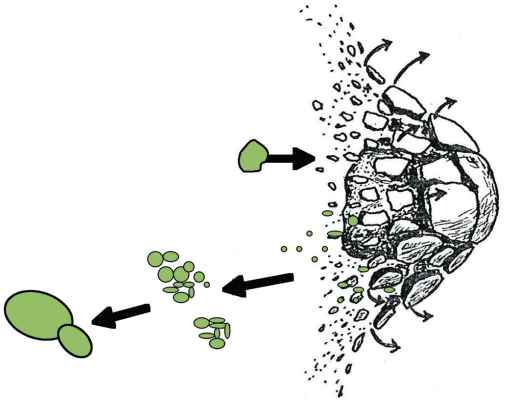
The other thing is that we could not send the exploration rover “MINERVA” on the surface of Itokawa. After being separated from the spacecraft, MINERVA succeeded in photographing a part of the solar paddle of Hayabusa. MINERVA worked normally, so no landing on the surface was really too bad. We expect that we can try again someday.



A photo of the backside of the solar paddle shot by MINERVA, which was separated from Hayabusa.

To the future

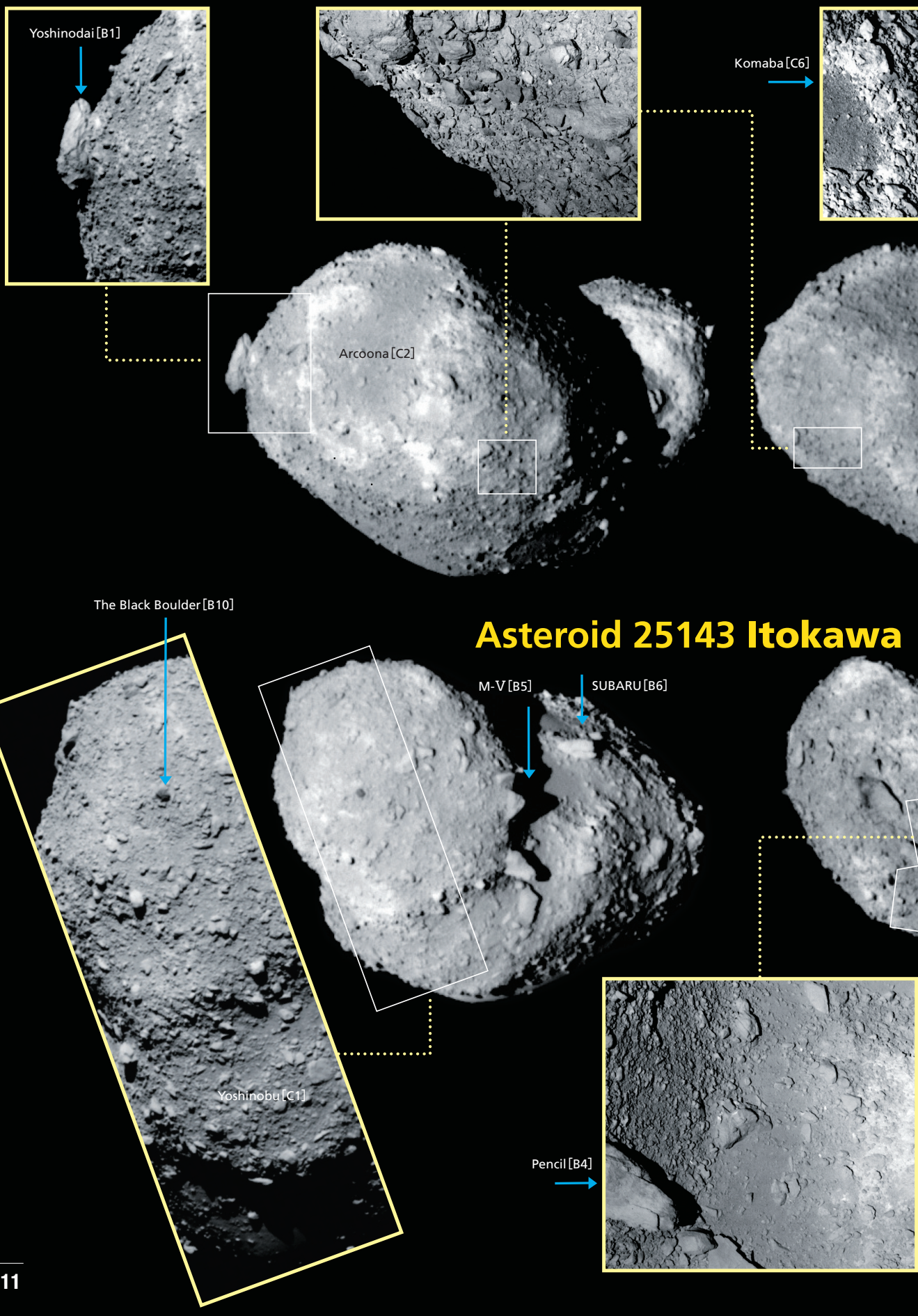
With the exploration of Hayabusa, a feature of the tiny asteroid like Itokawa, whose seize is about 500 m, was made known for the first time ever. Important findings, in particular, are that the density of Itokawa is about 1.9g/cm^3 and that the surface of Itokawa has the similar material as ordinary chondrite which falls in great number to the earth. From these results, it is estimated that the percentage of void inside Itokawa is no less than 40%. Thus, Itokawa more likely has a structure like the aggregate of "rubble." We can consider the formation scenario of Itokawa as follows: Asteroids once collided with each other around the inner region of the main asteroid belt. They destroyed with each other. The fragments pulled together by gravity to form lumps. Then the present Itokawa was formed by a collision of two of such lumps. Itokawa may tell the history of a collision of such small objects.

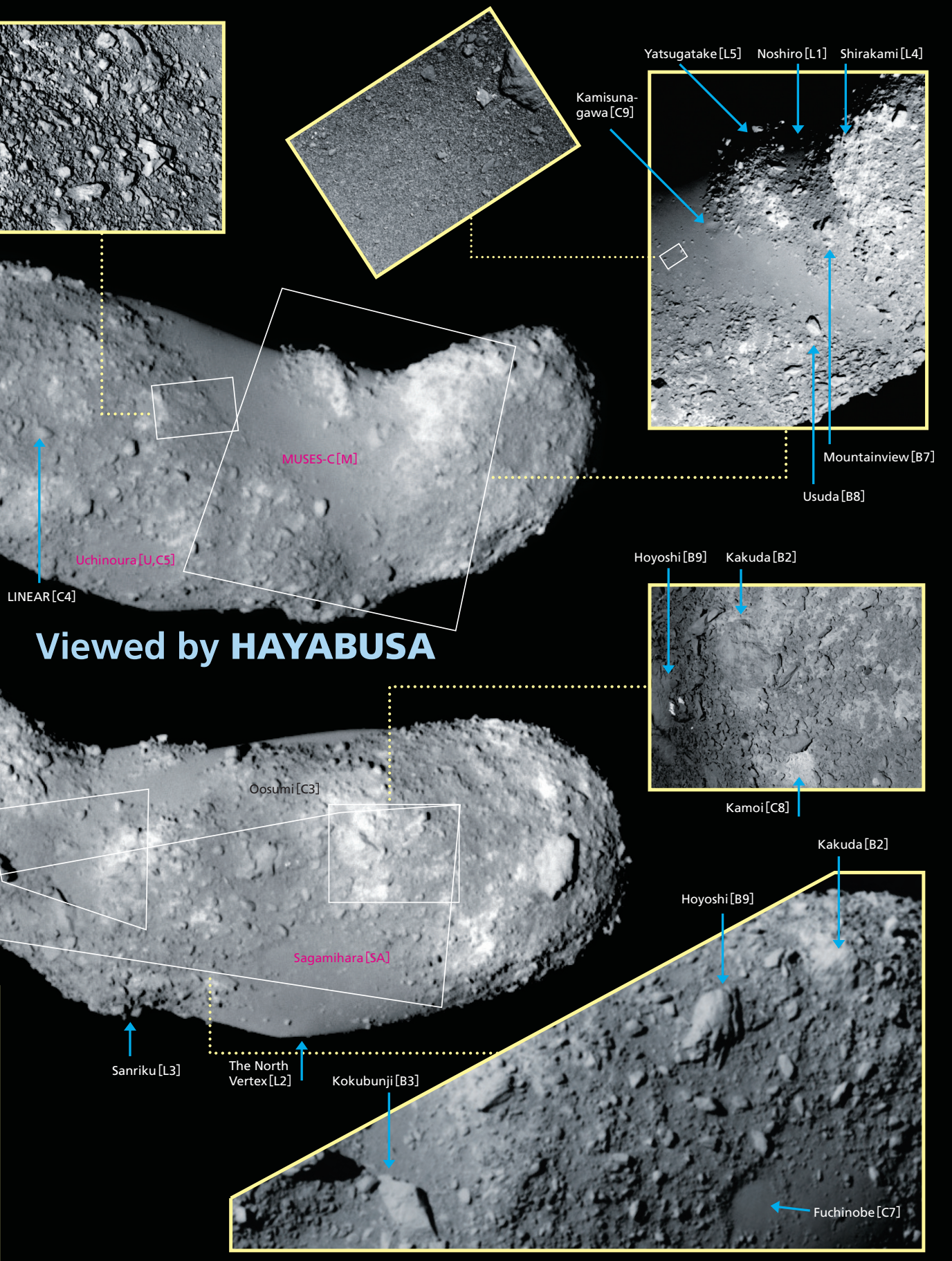


The scenario of the birth of the asteroid Itokawa: the fragments made by collision got together into two objects and they collided to combine into one.

Various discoveries about Itokawa were amazing. However, there are still a large number of asteroids in existence. There may be asteroids that are completely different from Itokawa. Of course, since it is impossible to explore all the asteroids, it is interesting from the aspect of science to, at first, study another type of asteroid different from Itokawa. Now, the "HAYABUSA-2," the successor of Hayabusa, is under consideration. The destination of "HAYABUSA-2" is a C-type asteroid that contains more organic matters while Itokawa is S-type with mainly rocky materials. We are looking forward to seeing what kind of world spreads out there.

Artistic image of the HAYABUSA-2 which aims at C-type asteroid. (Illustrated by Mr. Akihiro Ikeshita.)


Yoshinodai [B1]
Komaba [C6]
Arcoona [C2]
The Black Boulder [B10]
Asteroid 25143 Itokawa
M-V [B5]
SUBARU [B6]
Yoshinobu [C1]
Pencil [B4]



Viewed by HAYABUSA

Return of the Falcon

祈り

The story of "Hayabusa", a spacecraft to explore an asteroid

小惑星探査機 はやぶさ の物語

Second Edition

JASRAC V-0704317

DVD VIDEO NTSC

Return of the Falcon —— The story of "Hayabusa", a spacecraft to explore an asteroid——
祈り ——小惑星探査機 はやぶさ の物語 ——

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About the music used in the “Return of the Falcon”

Most of the music played in the DVD was released as a suite consisting of 11 music selections, “Lullaby of Muses” (Lyra Records/LRHL1003/LRHL1007) for praying success of the missions in autumn of 2002, when Hayabusa was still called MUSES-C of its code name.

On the night of November 18, 2001 when the brilliant Leonid meteor showered, I asked a jazz pianist, Ms. Emiko Kai, to compose the piece of music “Jupiter in rains” which depicted the night of the meteor shower, and to play live as BGM of the Internet relay while the meteor shower flowed. At that time, I was earnestly tackling the collaboration with a musician in order to find out the possibility for a new type of astronomical education. One day, after Leonid meteor fever went down, Dr. Hajime Yano of the MUSES-C mission team asked me “Could you also make music for an asteroid explorer?” and since I said, “Why don’t we make a suite where people can enjoy the missions complete process from launch to the return to the earth through music?” everything started.

I asked again Ms. Emiko Kai for a composition, an arrangement, and selection of a musician. And then I had Ms. Kai to visit ISAS, watch MUSES-C under assembly, and also take a lecture by Dr. Yano to understand the missions. On that occasion, Ms. Kai completed the suite which portrays MUSES-C as a boy who was going to leave for an adventure and expresses thoughts from not only the mission team but from all the people who wish success as a goddess. I also asked a vocalist, Ms. Yasuko Nakatani, who would express a goddess who warmly watched the boy by singing, for meeting with MUSES-C at ISAS to understand the people’ s thoughts. During the recording, I had Dr. Yano come to the studio, and asked him for the final check of the lyrics.

There are scenes where music is used in this DVD that is different from the music album “Lullaby of Muses.” This is the result of making the music rhythm fit the motion of Hayabusa during the process of adding music to CG, which was made based on the results of actual missions. Moreover, we adopted two music selections from a music album “Stairway to the stars” (Lyra Records/LRJZ1005) made for the total eclipse of the sun and the night of Leonid meteor since we could not pick up suitable music from only the suite because the video of the touchdown and various experiments prior to the touchdown were too long. In the two albums, leading Japanese jazz musicians did the wonderful performance. Moreover, Ms. Xiumin who is a leading player of Erhu, a Chinese musical instrument, expresses well the jet-black darkness of the universe in which Hayabusa continues to travel.

This music is a piece of scientific work for which the scientists, the players, and the astronomical educators cooperated in this way. Now, this wonderful video is added to the music. As for detailed descriptions of each music piece, I leave it to the original album, so in this DVD, please enjoy a beautiful sound and video while reading a science description of this booklet.

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Masami Okyudo
Student Center for Independent Research in the Sciences
Wakayama University

Return of the Falcon

The story of "Hayabusa", a spacecraft to explore an asteroid

Second Edition

祈り

小惑星探査機 はやぶさ の物語

This video was made to help you relax while watching the story of exploration of the asteroid Itokawa by the spacecraft “Hayabusa” with scientific accuracy. The melody of beautiful jazz, which is played through most of the video, was composed by Ms. Emiko Kai as a promotional song when Hayabusa was still called MUSES-C. The music represents the image of a Muse (goddess), who is a symbol of the thoughts of people who operate Hayabusa and all the people who cheer on Hayabusa, gently watching the challenge of a boy Hayabusa. Please prepare your favorite refreshment, a glass of wine, juice, or a cup of coffee, and enjoy this video.

Numbers :
Let's fly / Lift off / Spica / Lullaby of Muses / A little bit, little bit dancing
Stranger / Space passion / My rose / Chance / Back to my arms / Adieu

Stranger, Adieu : in the album of "Stairway to the stars"(LRJZ1005)
Others : in the album of "Lullaby of Muses"(LRHL1003 / LRHL1007)

JAXA
Japan Aerospace Exploration Agency

JSpEC
JAXA Space Exploration Center

ISAS
Institute of Space and Astronautical Science

Produced by Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA)