Candidates for landing sites for the Hayabusa2 mission

August 23, 2018

JAXA Hayabusa2 Project

Topics

Regarding Hayabusa2:

- Candidates for landing sites for touchdown, MASCOT, and MINERVA-II

Contents

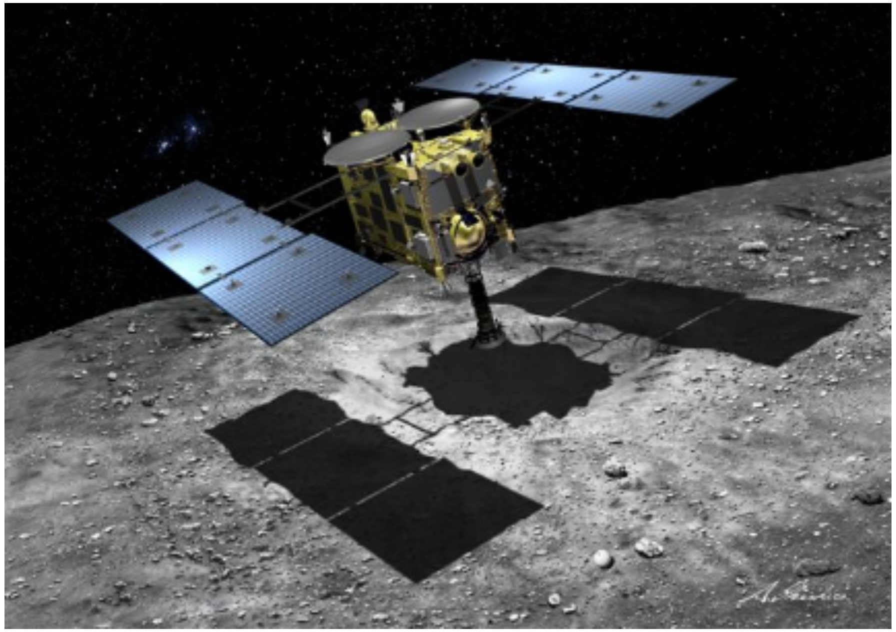
Overview of Hayabusa2

Objective
We will explore and sample the C-type asteroid Ryugu, which is a more primitive type than the S-type asteroid Itokawa that Hayabusa explored, and elucidate interactions between minerals, water, and organic matter in the primitive solar system. By doing so, we will learn about the origin and evolution of Earth, the oceans, and life, and maintain and develop the technologies for deep-space return exploration (as demonstrated with Hayabusa), a field in which Japan leads the world.

Expected results and effects
・By exploring a C-type asteroid, which is rich in water and organic materials, we will clarify interactions between the building blocks of Earth and the evolution of its oceans and life, thereby developing solar system science.
・ Japan will further its worldwide lead in this field by taking on the new challenge of obtaining samples from a crater produced by an impacting device.
・We will establish stable technologies for return exploration of solar-system bodies.

Features:
・World's first sample return mission to a C-type asteroid.
・World's first attempt at a rendezvous with an asteroid and performance of observation before and after projectile impact from an impactor.
・Comparison with results from Hayabusa will allow deeper understanding of the distribution, origins, and evolution of materials in the solar system.

International positioning：
・Japan is a leader in the field of primitive body exploration, and visiting a type-C asteroid marks a new accomplishment.
・This mission builds on the originality and successes of the Hayabusa mission. In addition to developing planetary science and solar system exploration technologies in Japan, this mission develops new frontiers in exploration of primitive heavenly bodies.
・NASA too is conducting an asteroid sample return mission, OSIRIS-REx (launch: 2016; asteroid arrival: 2018; Earth return: 2023). We will exchange samples and otherwise promote scientific exchange, and expect further scientific findings through comparison and investigation of the results from both missions.



(Illustration: Akihiro Ikeshita)

Hayabusa 2 primary specifications

Mass	Approx. 609 kg
Launch	3 Dec 2014
Mission	Asteroid return
Arrival	27 June 2018
Earth return	2020
Stay at asteroid	Approx. 18 months
Target body	Near-Earth asteroid Ryugu

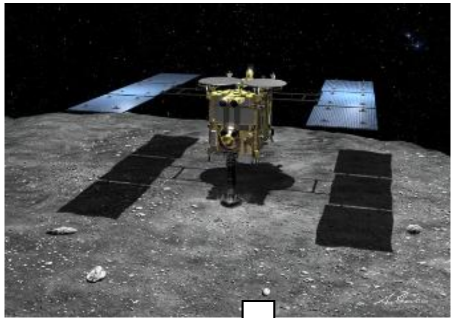
Primary instruments
Sampling mechanism, re-entry capsule, optical cameras, laser range-finder, scientific observation equipment (near-infrared, thermal infrared), impactor, miniature rovers.

Mission flow

Launch
3 Dec 2014

Earth swing-by
3 Dec 2015

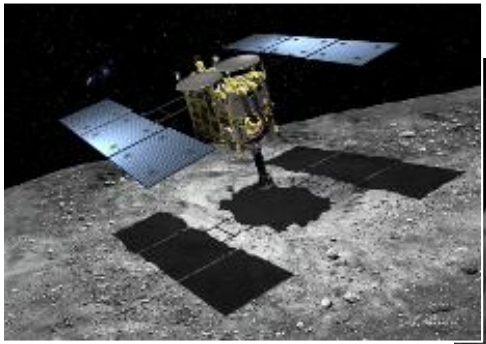
Arrival at asteroid
June 27, 2018



Examine the asteroid by remote sensing observations. Next, release a small lander and rover and also obtain samples from the surface.

Use an impactor to create an artificial crater on the asteroid's surface

Depart asteroid
Nov–Dec 2019



After confirming safety, touchdown within the crater and obtain subsurface samples

Earth return
late 2020

Sample analysis

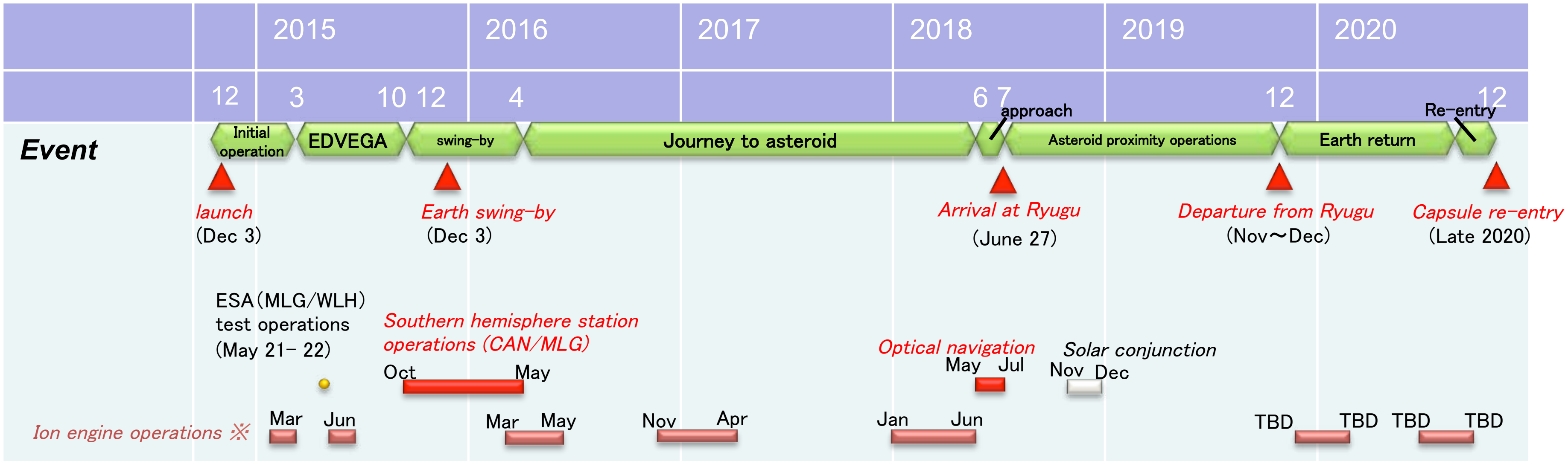
(Illustrations: Akihiro Ikeshita)

1. Current project status & schedule overview

Current status：

- On August 5, we began operations for gravity measurement, approaching Ryugu to an altitude minimum of 851m at around 08:10 JST on August 7. The spacecraft then returned to the home position on August 10.
- Based on the data obtained to date, we investigated possible landing points.
- BOX-B operations began on August 18 (scheduled to return to BOX-A on September 7).

Schedule overview:

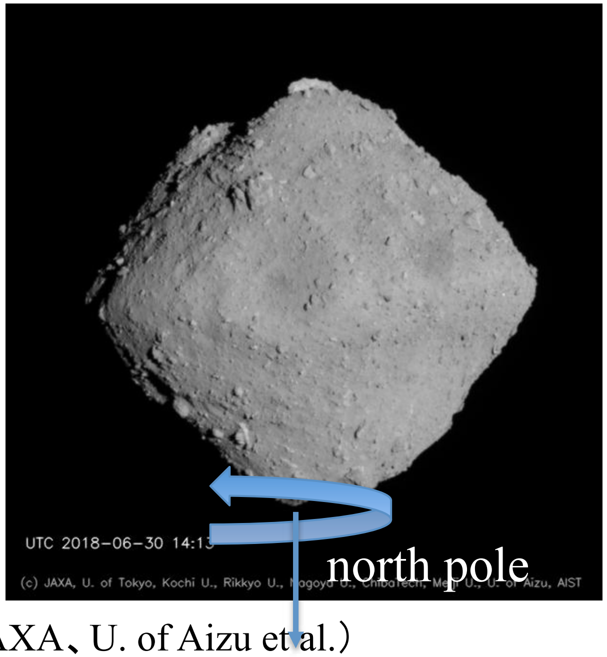


Points to note in this document

Pay attention to the orientation of the asteroid!

Public images so far have shown the northern direction of the Solar System (direction of the Earth's North Pole) pointing upwards.

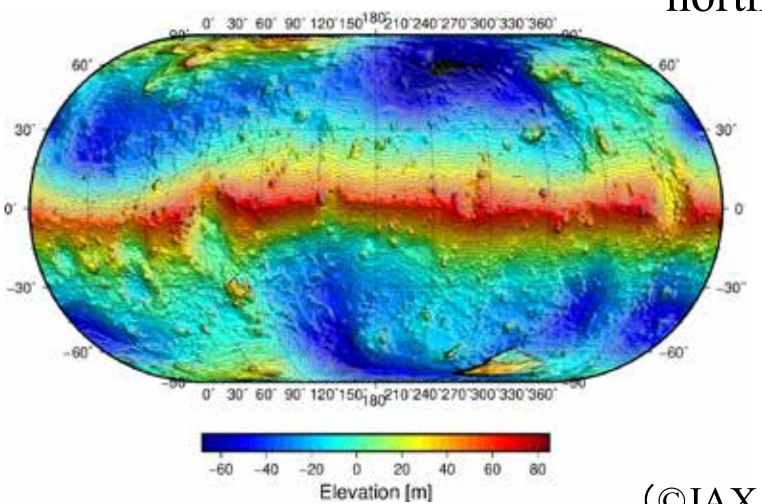
In this document, like a typical map, north is drawn pointing upwards. As Ryugu rotates backwards, Ryugu's "north" is at the bottom of the left-hand figure, but the top in this map (top and bottom are reversed).
From now on, public images also show the northern direction of Ryugu pointing upwards.



(©JAXA、U. of Aizu et al.)

Ryugu has a reverse rotation (retrograde)

north pole ↑



(©JAXA)

Example of a Ryugu "map"

2. Landing site candidates and expected dates

Landing Site Selection（LSS) conference:

- Held on August 17, 2018
- 109 attendees (including remote participants)
- 39 participants from overseas (14 from DLR, 2 from CNES and 2 from NASA)
- Discussion took place from 10 am to 7 pm.

↓

Determined candidate landing points for spacecraft touchdown, MASCOT & MINERVA-II

August 17, 2018: Group photo of LSS meeting

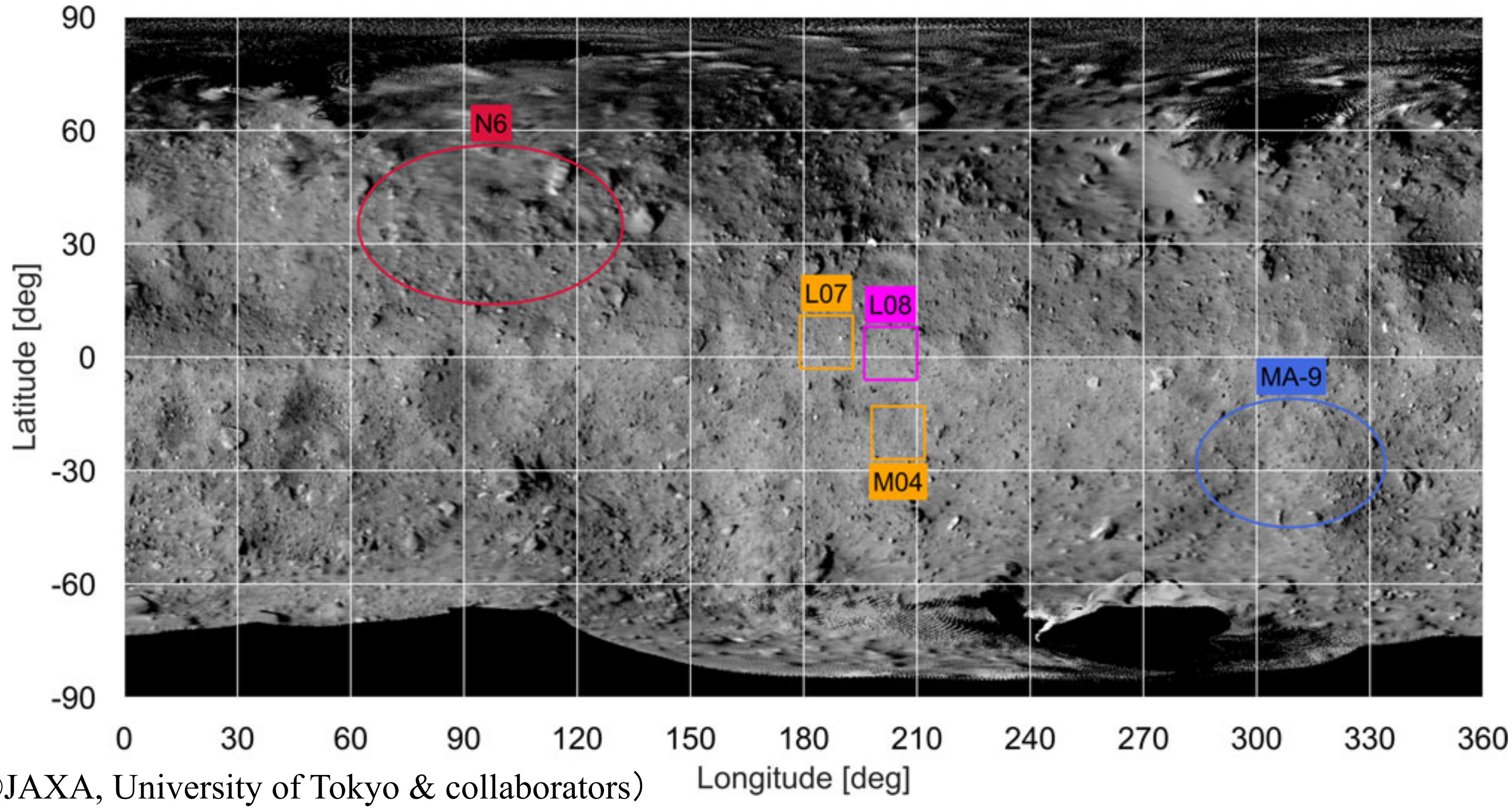
2. Landing site candidates and expected dates

Determined landing site candidates

Touchdown : L08（backup：L07、M04）

MASCOT : MA-9

MINERVA-II-1 : N6



2. Landing site candidates and expected dates

Determined landing site candidates

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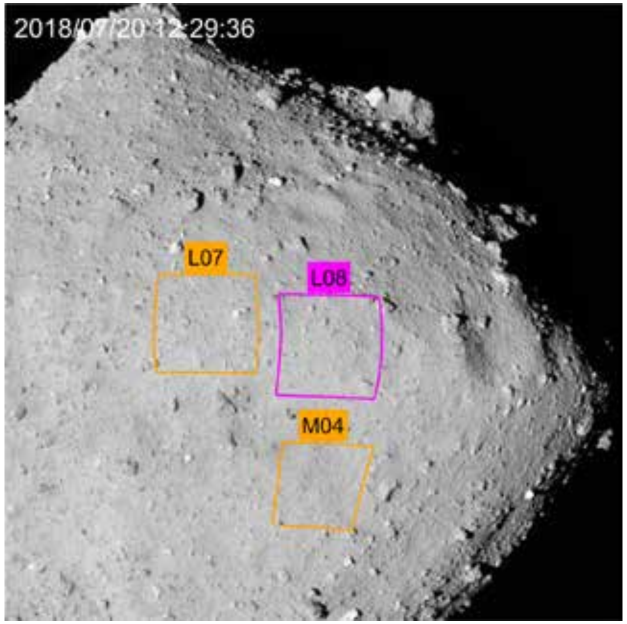
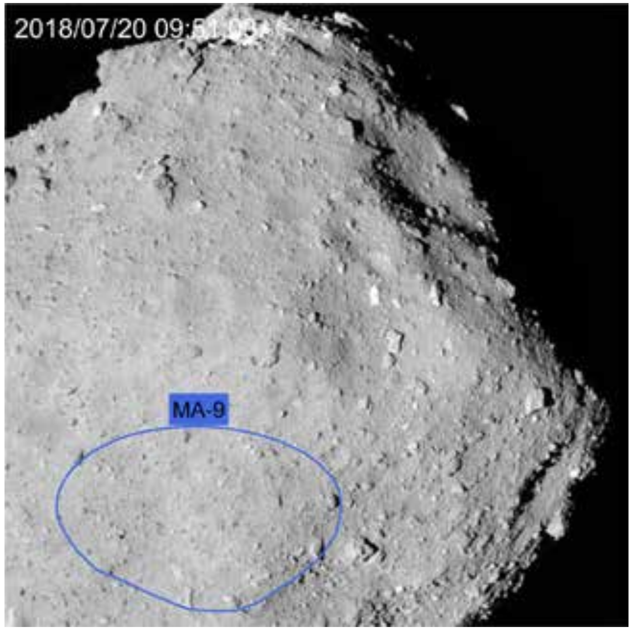
MASCOT : MA-9

MINERVA-II-1 : N6

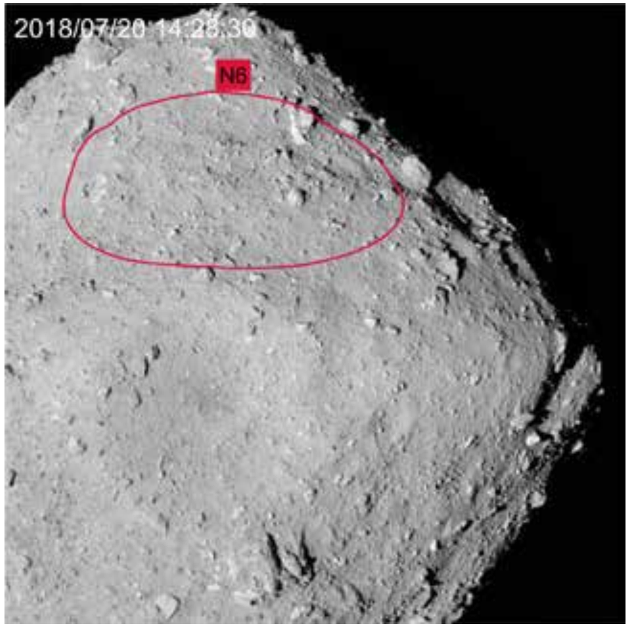
Touchdown



MASCOT



MINERVA-II-1



2. Landing site candidates and expected dates

Operation Schedule

Touchdown 1 rehearsal 1:	September 11 ~ 12
(Arrival at lowest altitude : September 12)	
MINERVA-II-1 operation:	September 20 ~ 21
(MINERVA-II-1 separation：September 21)	
MASCOT operation:	October 2 ~ 4
(MASCOT separation：October 3)	
Touchdown 1 rehearsal 2:	mid-October
Touchdown 1:	late-October

Note: date of operations may be changed.

3. Selection of touchdown site candidates

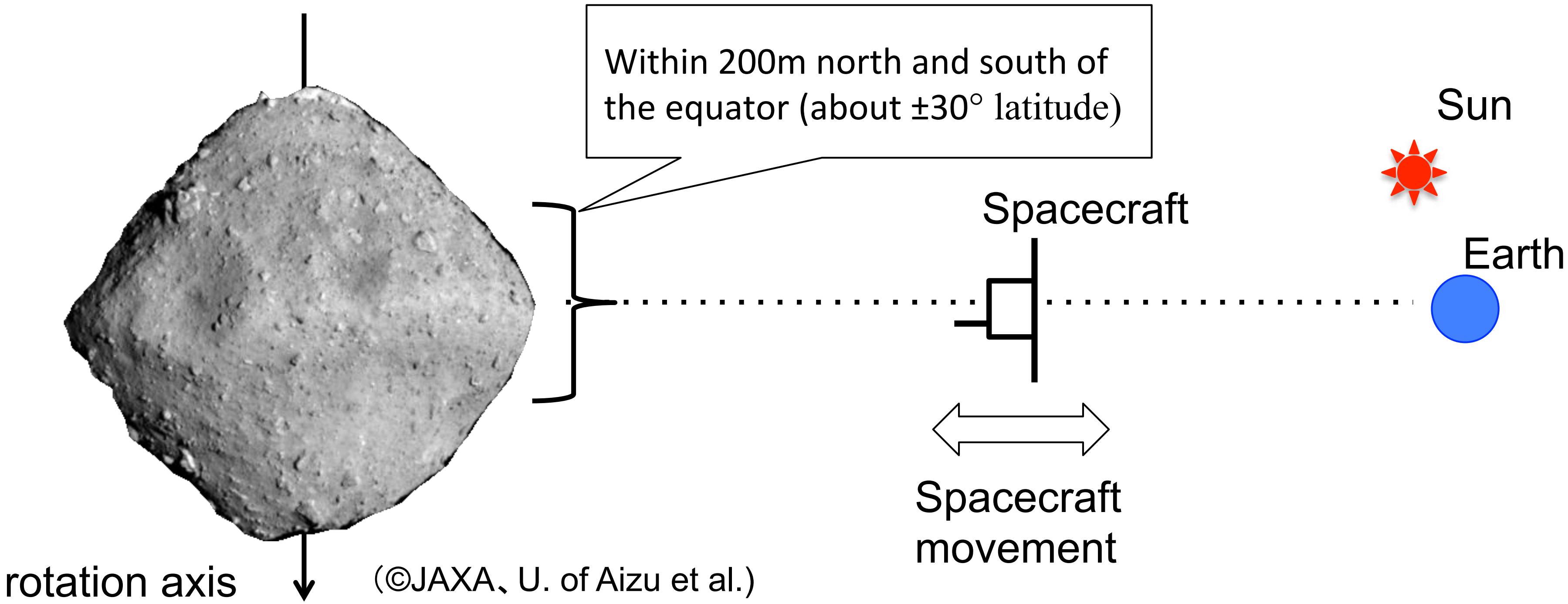
Prerequisites for touchdown candidate points, part 1

Range on the celestial body where the spacecraft can land

The spacecraft can move along the line connecting the Earth and Ryugu.

↓

The region where the spacecraft can land is the area within about 200 m to the north and south of Ryugu's equator (range of about ±30° latitude)



3. Selection of touchdown site candidates

Prerequisites for touchdown candidate points, part 2

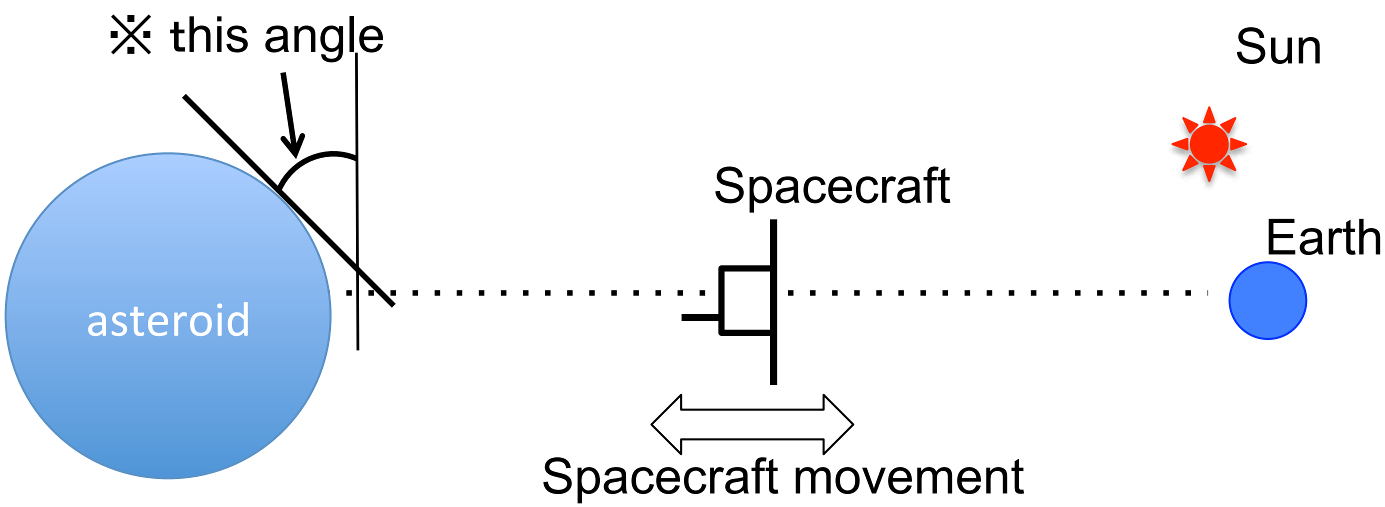
<u>Surface conditions suitable for landing</u>

(1) Average slope within 30° ※ ← Limit due to orientation of solar panels

(2) Flat region with 100m diameter ← Navigation guidance accuracy

(3) Boulder height less than 50cm ← Length of sampler horn

(4) Absolute temperature less than 370K（97℃）
← Within operating temperature range of equipment



3. Selection of touchdown site candidates

Procedure of the selection of landing site candidates

Box-A, Box-C, Mid-alt

Step 1:Safety score analyses

- ☐ Rotation model
- ☐ Shape model

------ Choose safe landing site based on attitude of probe, surface inclination, terrain conditions etc.

↓

Step 2:Visual evaluation

- ☐ Optical images

------- From the images from the Optical Navigation Cameras, investigate the boulder coverage, presence of obstacles, surface flatness etc needed to chose the right place.

↓

Step 3:Feasibility analyses

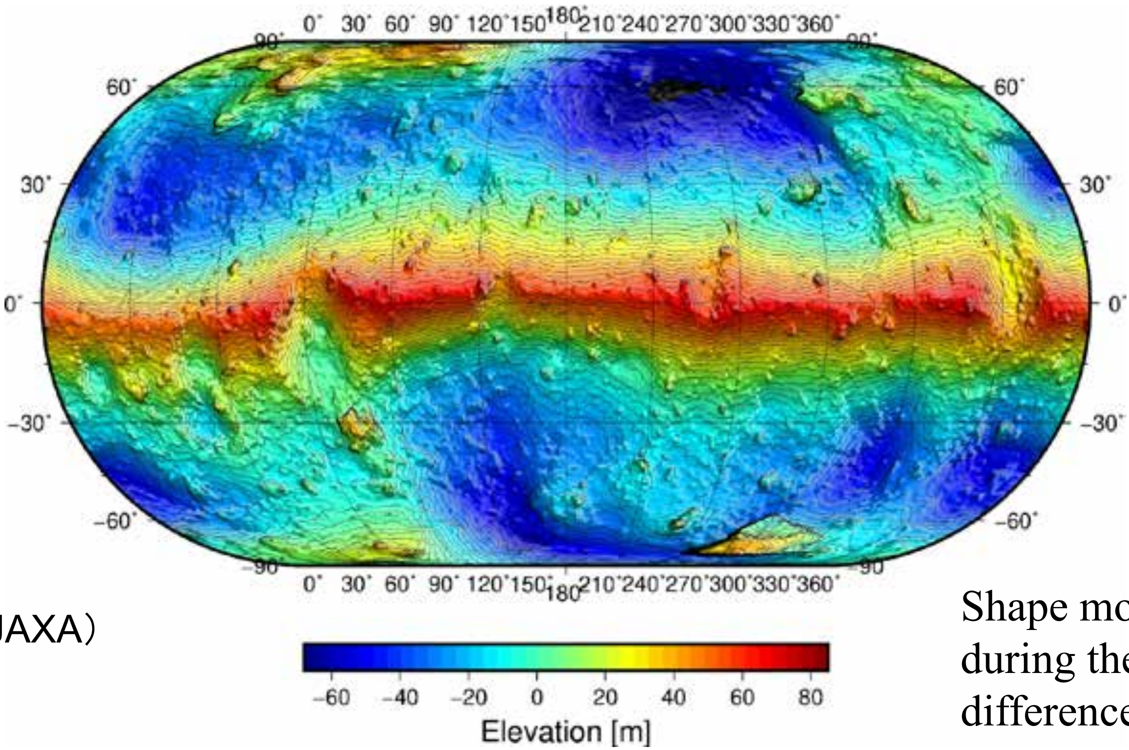
- ☐ Temperature map
- ☐ Longitude accessibility
- ☐ Boulder density

------- Confirm temperature and operation conditions for the time of landing. Precisely examine the distribution of boulders.

Box-A: alt. 20km
Box-C : alt. 6km
Medium altitude : alt. 5km

3. Selection of touchdown site candidates

Narrow down touchdown candidates: Step 1, from shape model



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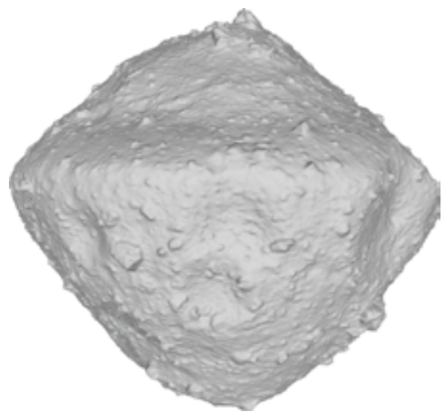

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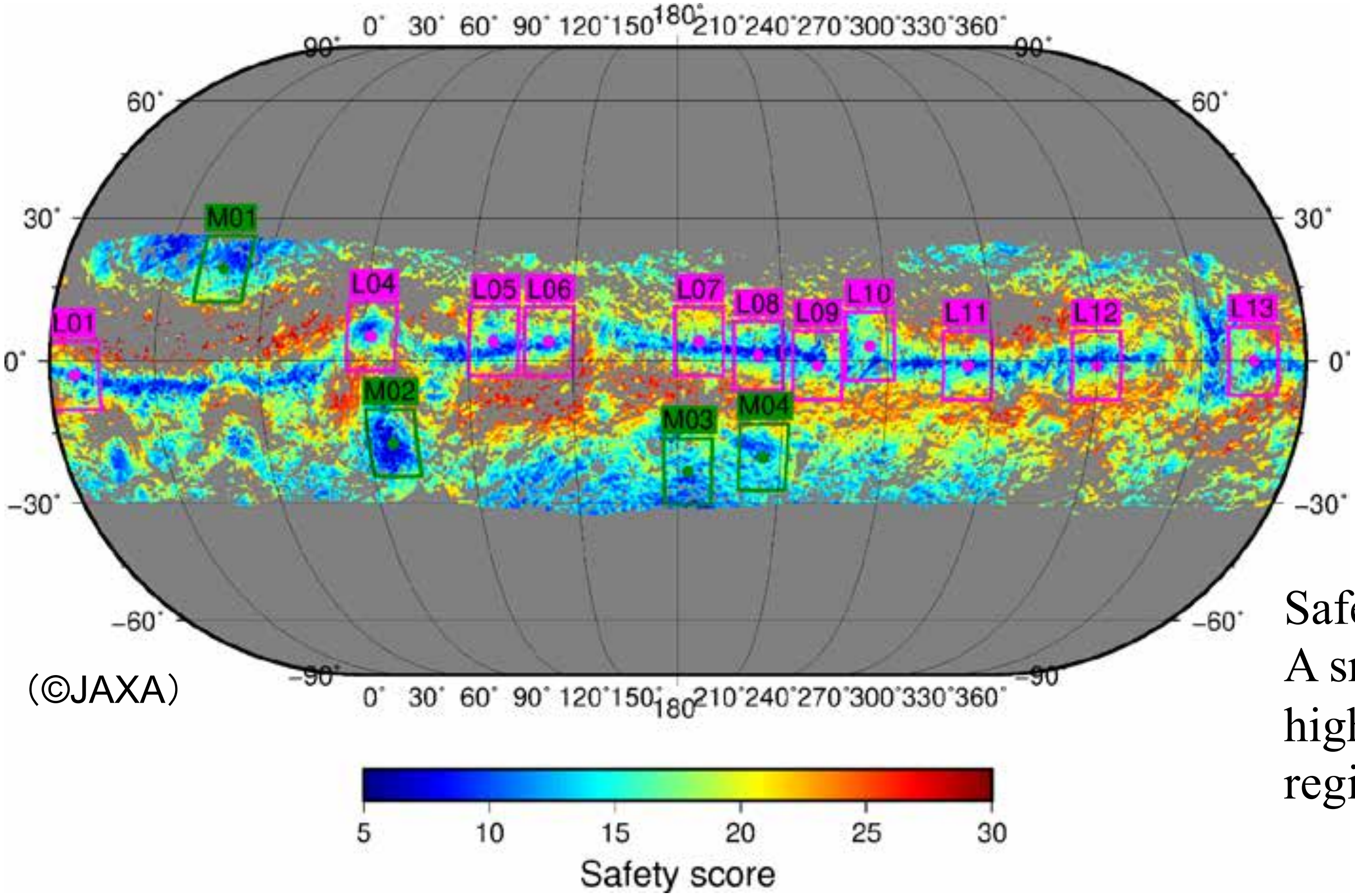
Shape model (right) based on data acquired during the Medium Altitude Operation, and the difference in surface elevation on Ryugu (left)

Safety score for each point is calculated by using the shape model.
Items considered:
- Sun angle (angle between +z axis of S/C and the sun)
- Slope angle
- Roughness

→ The safety score value can aid selecting a safe location.

3. Selection of touchdown site candidates

Narrow down touchdown candidates: Step 1, from shape model



100m×100m area.
(14° x 14° in lat., long.)

Safety score distribution. A smaller value indicated higher safety. Gray indicates regions above a score of 30.

Select candidates for landing sites from locations with a high degree of safety (low safety value score).

11 low latitude ("L") and 4 middle latitudes ("M") were selected.

3. Selection of touchdown site candidates

Narrow down touchdown candidates: Step 2, from images

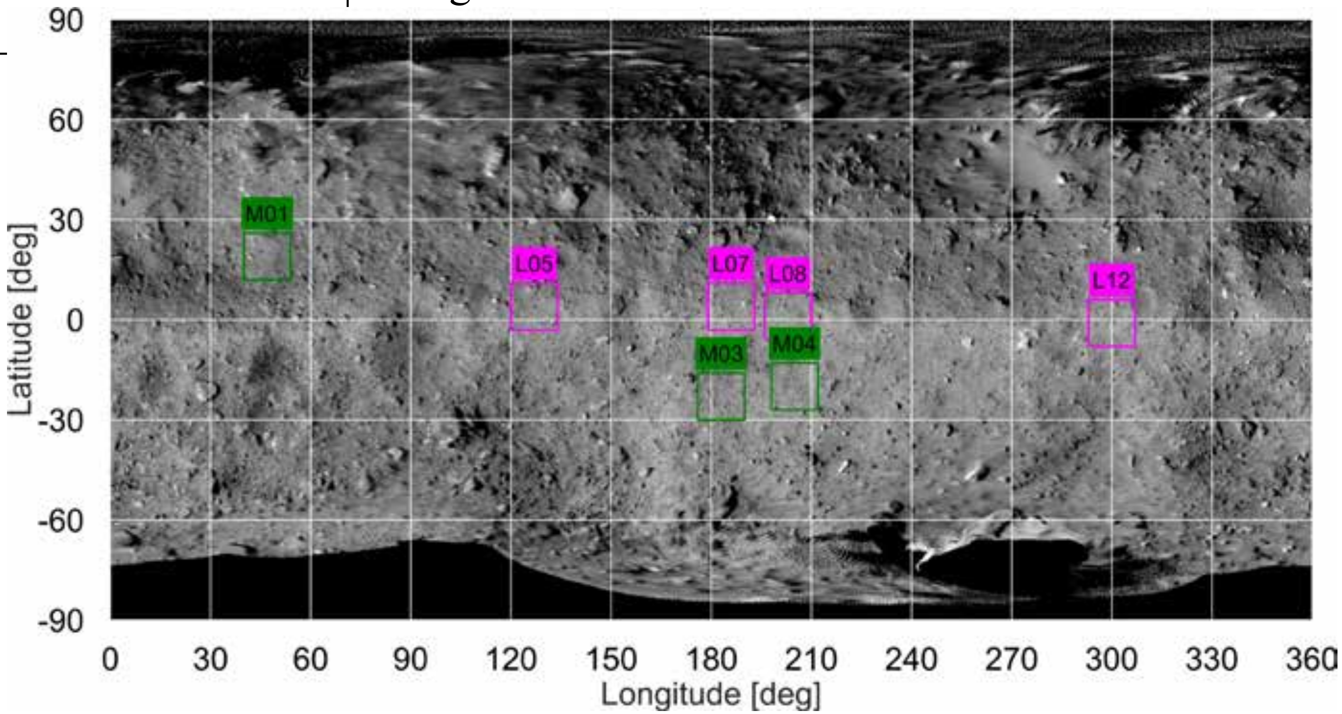
Choose candidate sites from images captured with the Optical Navigation Cameras:

Features to note:

- Boulder coverage
- Obstacles on the east side※
- flatness

Narrow down to four low latitude (“L”) and three mid-latitude (“M”) sites.

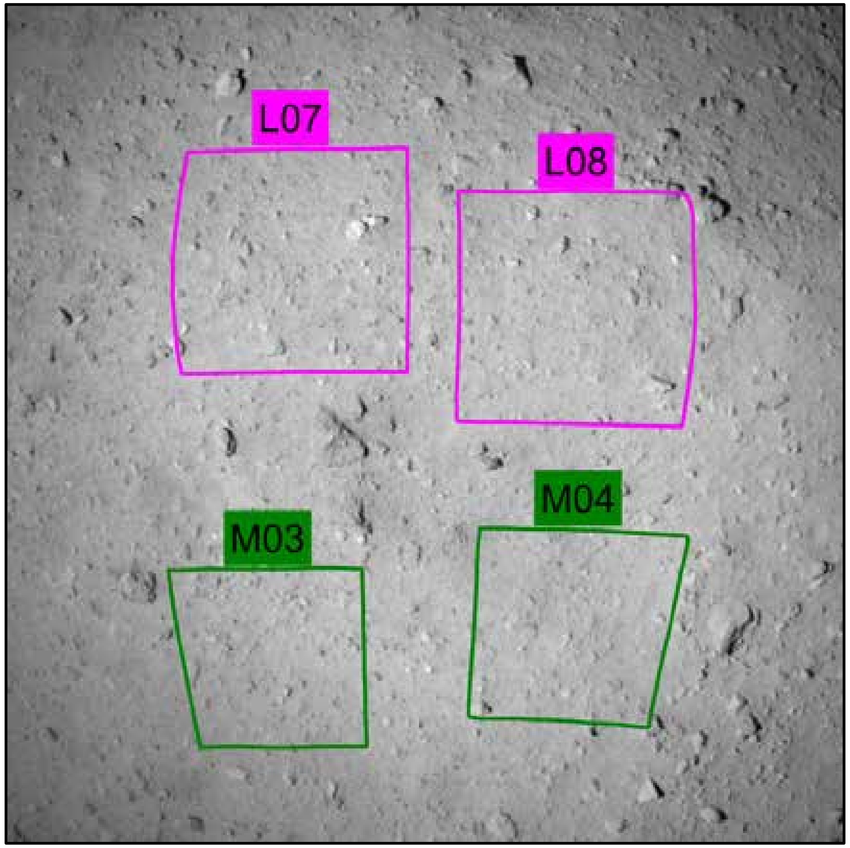
※Since the spacecraft will approach from the east when landing, obstacles on the east side are dangerous.

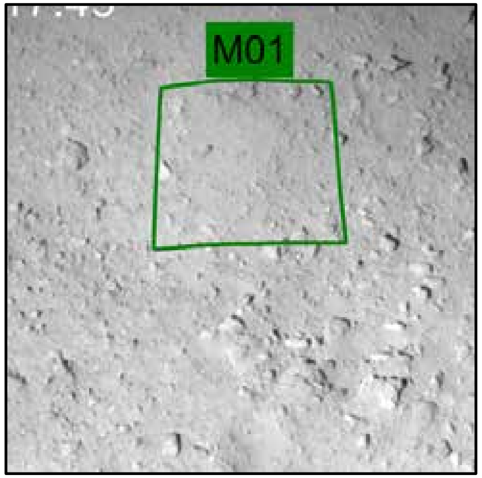


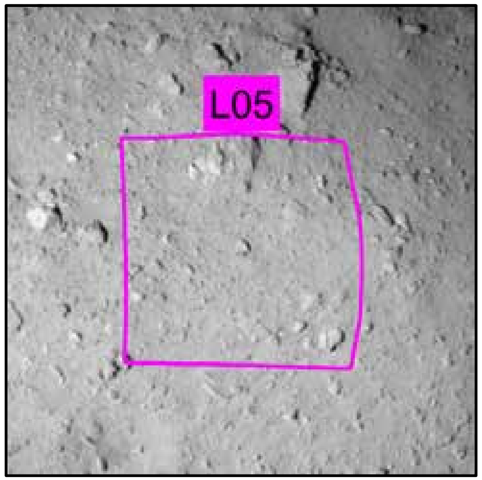
3. Selection of touchdown site candidates

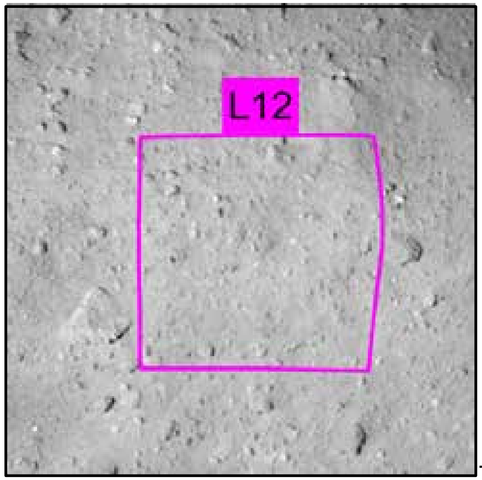
Narrow down touchdown candidates: Step 2, from images

Candidate sites: four low latitude (“L”) and three mid-latitude (“M”)









3. Selection of touchdown site candidates

Narrow down touchdown candidates: Step 3, feasibility

Further narrowing down from 7 candidates (4 low latitude, 3 mid-latitude)

Surface temperature: absolute temperature of 370 K or less.

→ 7 candidate points all OK

Longitude dependence of surface approach: communication with ground tracking stations uninterrupted

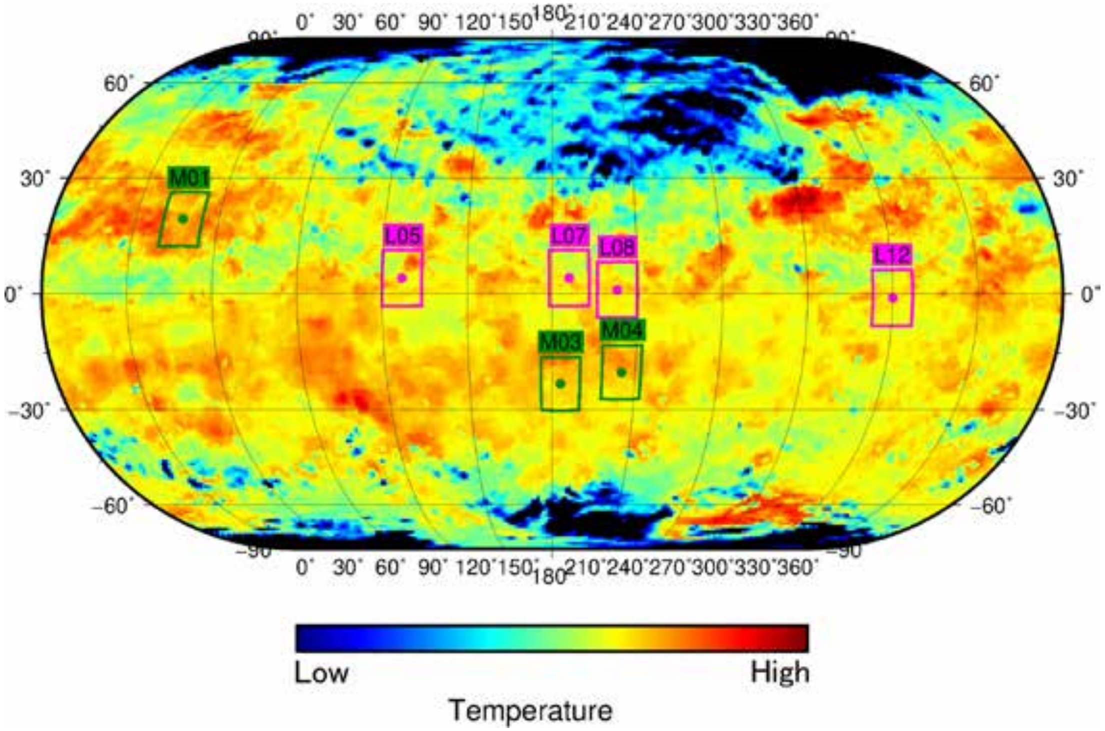
↓

7 candidate points all OK

Boulder number density: less boulders are preferred

↓

Compare the 7 possible sites



Surface temperature distribution map

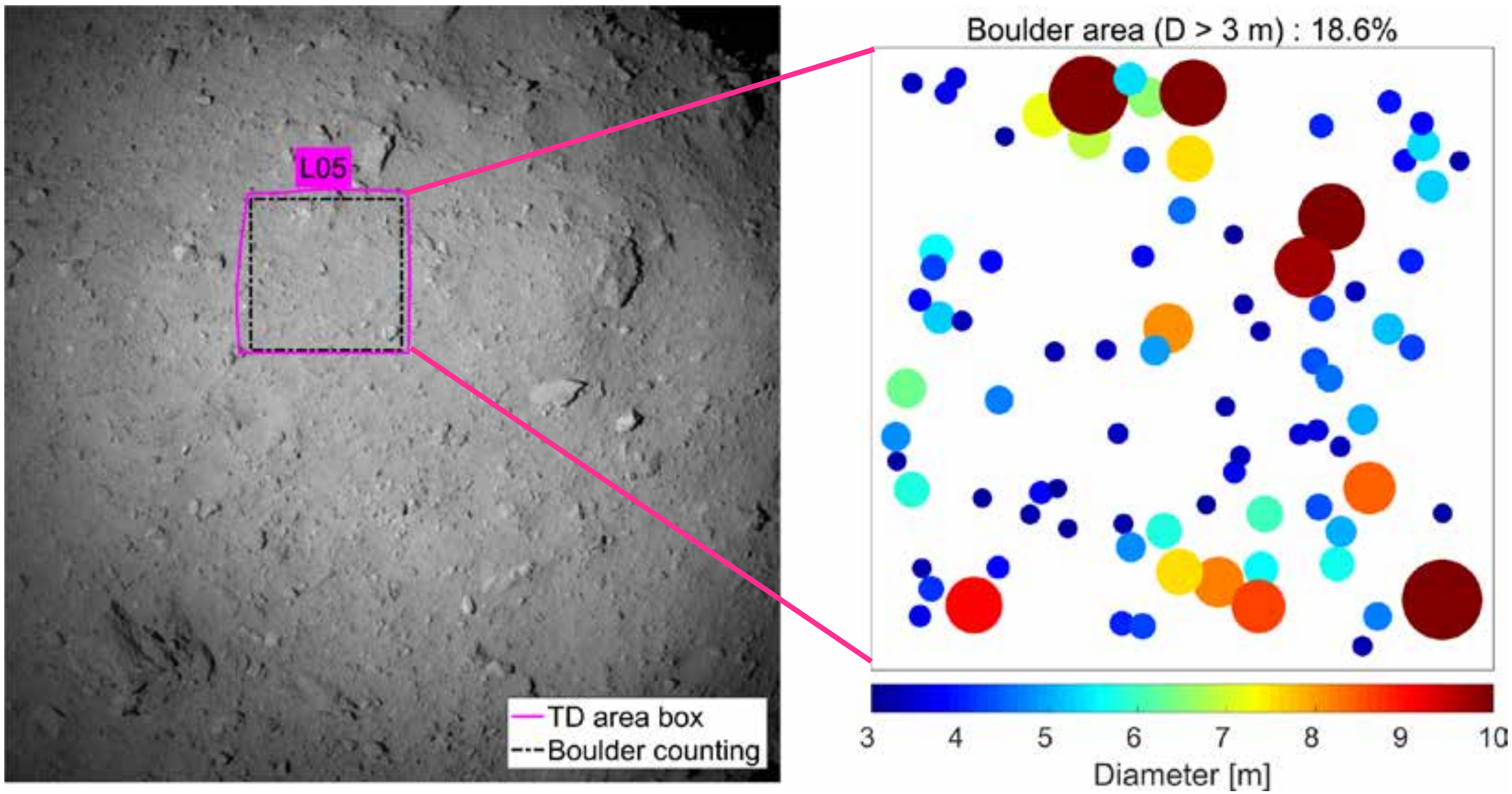
(©JAXA、Ashikaga U et al.)

3. Selection of touchdown site candidates

Narrow down touchdown candidates: Step 3, feasibility

Further narrowing down from 7 candidates (4 low latitude, 3 mid-latitude)

Create boulder map and check boulder coverage



Example boulder map

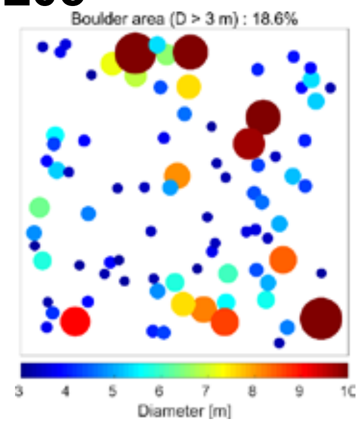
3. Selection of touchdown site candidates

Narrow down touchdown candidates: Step 3, feasibility

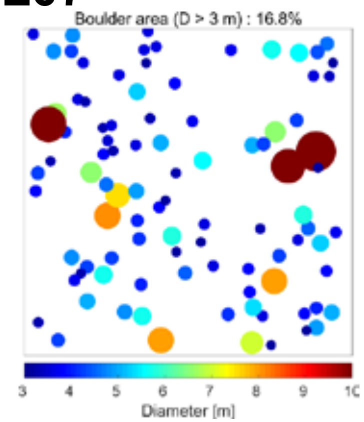
Further narrowing down from 7 candidates (4 low latitude, 3 mid-latitude)

Creating boulder maps

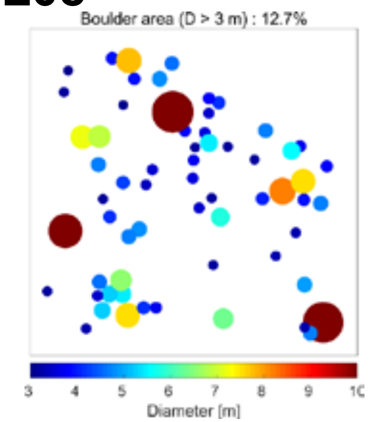
L05



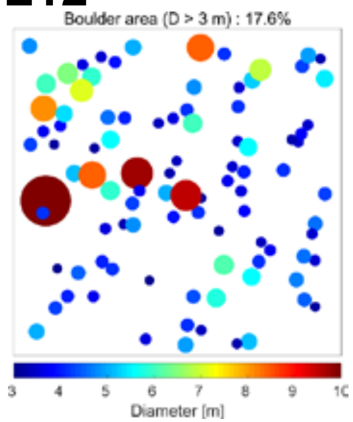
L07



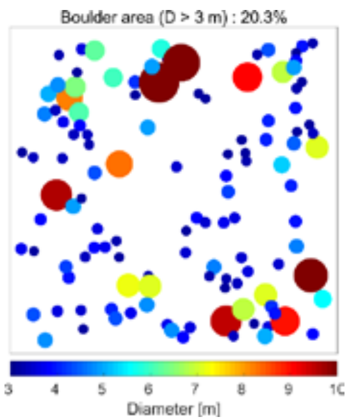
L08



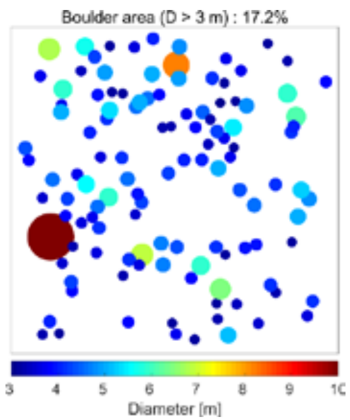
L12



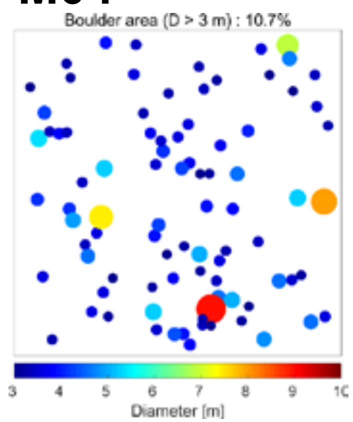
M01



M03



M04



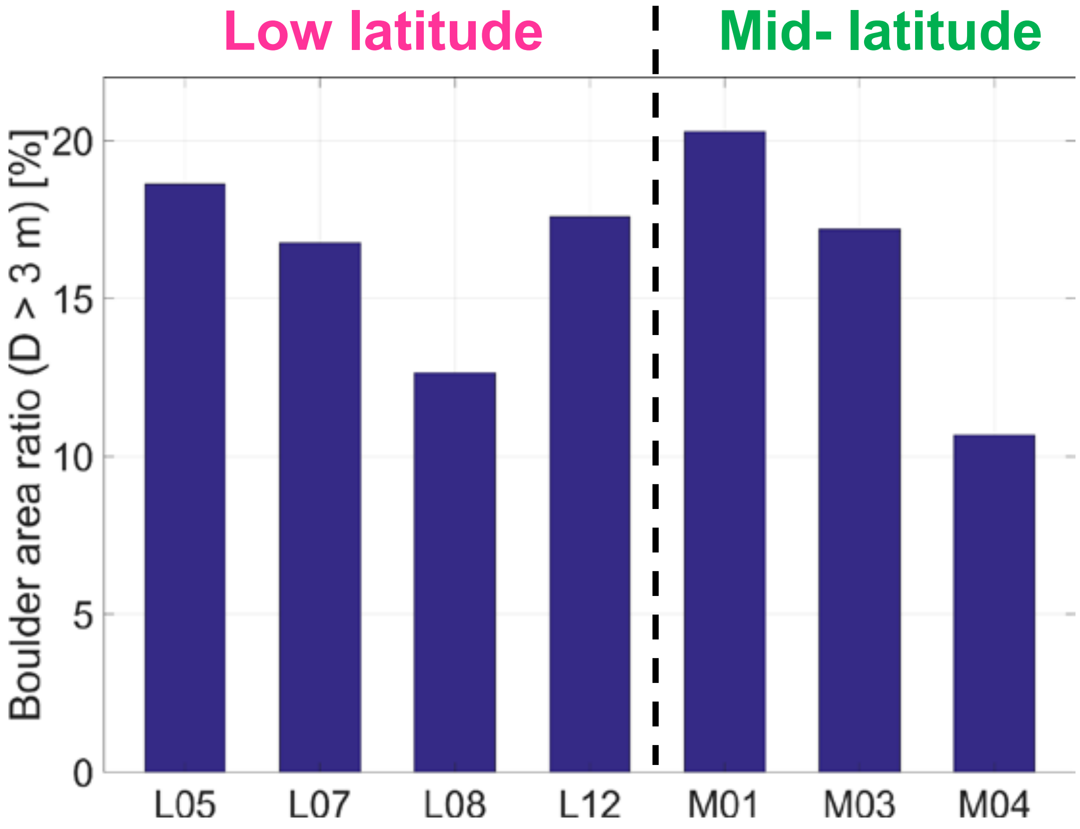
Distribution of boulders. The size of boulders with a diameter greater than 3m is indicated by marker size and color. Brown is for boulders larger than 10m.

3. Selection of touchdown site candidates

Narrow down touchdown candidates: Step 3, feasibility

Further narrowing down from 7 candidates (4 low latitude, 3 mid-latitude)

Determining boulder coverage



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At low latitudes, L08, L07 in order. At mid-latitudes, M04

Lower latitudes are preferable for ease of landing

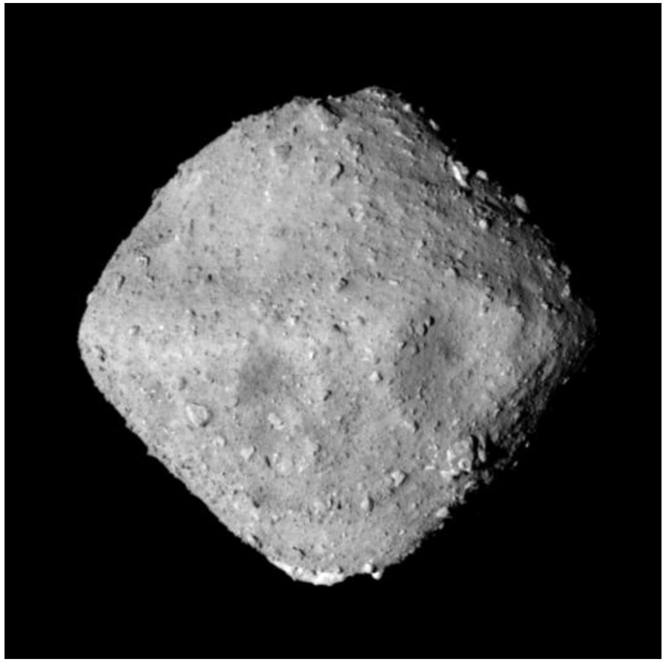
Touchdown candidate point is L08 (backup: L07, M04)

※Touch down point will be fixed by considering the results of the first rehearsal operation that will be done before the touchdown.

4. Science discussions for touchdown site candidates

Features of Ryugu

- Top shape with a very circular equatorial bulge
- Radius: mean ～450 m
  （equatorial ～500 m、polar ～440 m）
- Mass: ～450 million ton（GM～30 m^3s^{-2})※
- Rotation axis: (λ, β) = (180 °, -87 °)
- Obliquity: ～8°
- Rotation period：P = 7.63 hours
- Reflectance factor（v-band）: 0.02



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- Crater number density: as much as those on Itokawa and Eros
- Many boulders: the largest near the south pole is ~130 m across
- Optical spectra: flat spectra, bluer in equatorial bulge and poles
- NIR spectra: uniform flat (slightly redder) spectra with weak water absorption
- brightness temperature：strong roughness effect (flat diurnal Temperature variation), higher thermal inertia in the equatorial bulge

（※The gravity at the equator is eighty-thousandth of the Earth and a few times of Itokawa)

4. Science discussions for touchdown site candidates

Scientific evaluation points of landing site candidates

■ Point 1: surface properties

・Examine surface temperature and thermophysical properties using the Thermal Infrared Imager data.

・Examine composition differences using spectral data from the Near Infrared Spectrometer.

・Examine terrain, geology and space weathering from different wavelength images from the Optical Navigation Camera.

↓

※ Evaluate potential scientific merit.

■ Point 2: safety

・Examine size and spatial distribution of boulders (from images and laser altimeter data).

↓

※ Evaluate safety by estimating the number of small boulders from the boulder size distribution.

■ Point 3: sample yield

・Estimate surface grain sizes from observational data from the Thermal Infrared Imager.

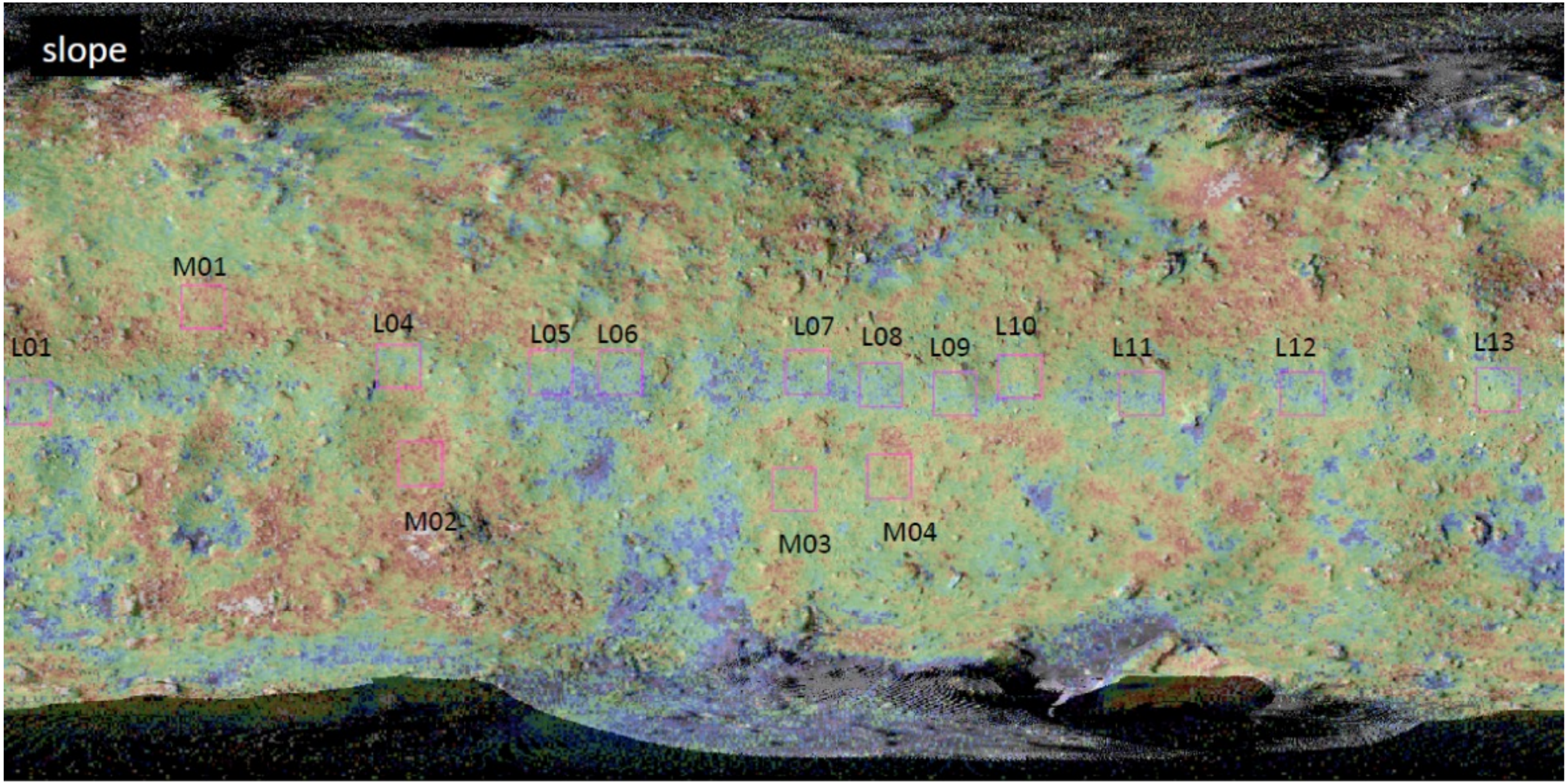
↓

※ From the particle size of surface regolith, evaluate where the maximum amount of sample can be gathered.

4. Science discussions for touchdown site candidates

The points for scientific evaluation of the landing site candidates: one example from observation data.

ONC-T spectral slope map (Box-C)



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4. Science discussions for touchdown site candidates

Summary of the scientific evaluation of landing point candidates

Candidate site	Point 1 surface properties	Point 2 safety	Point 3 Sample yield	Total
L5	22	29	12	63
L7	22	31	12	65
L8	22	31	12	65
L12	22	31	11	64
M1	21	33	13	67
M3	21	30	13	64
M4	21	33	13	67

Although no big difference in evaluation, L08 & L07 are good for low latitude (L). M1 & M4 are good if mid-latitude (M) is preferred.

Point 1: Surface temperature, visible / near-infrared spectrum etc. There is no big differences across the surface, which is almost uniform. However, there are minor differences. Spectral characteristics indicate that lower latitudes may contain more diverse particles.

Point 2: Safety is evaluated from information such as number density of boulders, estimated number of smaller boulders and surface roughness.

Point 3: Mid-latitudes (M) seem to have many smaller sized particles, which is expected to increase the sample yield.

4. Science discussions for touchdown site candidates

Summary of the scientific evaluation of landing point candidates

Scientifically important points:

（1）Difference in mixing ratio of Ryugu surface material has a low dependence on location.

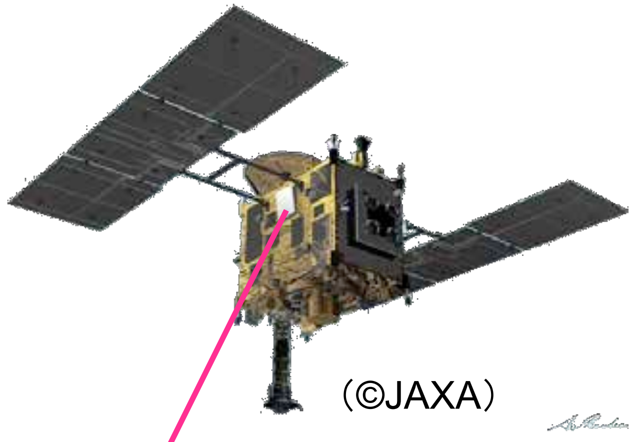
（2）A diversity of different materials are present mixed together on Ryugu's surface.

（3）Regardless of where the sample is collected, there is a high possibility of gathering diversified materials that represent the whole of Ryugu.

5. Selection of landing site candidates for MASCOT

MASCOT (Mobile Asteroid Surface Scout)

- Created by DLR (German Aerospace Center) and CNES (French National Centre for Space Studies)
- Small lander with mass approx. 10 kg
- Carries four scientific instruments
- Can move only once, by jumping

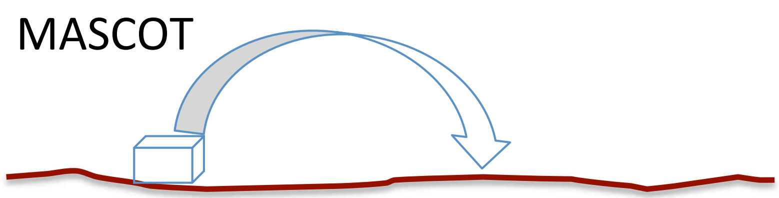


(©JAXA)

Flight model (© DLR)

Scientific instruments aboard MASCOT

Device	Function
Wide-angle camera (MASCAM)	Imaging at multiple wavelengths
Spectroscopic microscope (MicrOmega)	Investigation of mineral composition and characteristics
Thermal radiometer (MARA)	Surface temperature measurements
Magnetometer (MASMAG)	Magnetic field measurements



5. Selection of landing site candidates for MASCOT

Criteria for the selection of landing site candidates for MASCOT

- Probability to land outside the candidates for touchdown > 95 %
- Probability to have RF link during at least 40% of the asteroid period > 90 %
- Probability to have a good daylight ratio (between 40% and 70%) > 90 %
- Selection among remaining candidates to have one candidate per reachable and suitable zone, in northern as well as in southern hemisphere
- No overlap with the landing site candidates for MINERVA-II

⇩

computed 10,000 ～ 100,000 Monte-Carlo trials

⇩

10 candidates

⇩ ← Further conditions

6 candidates & prioritization

Further conditions

- Temperature (illumination, orientation, heating, prior separation, asteroid surface temperature, night temperature underneath MASCOT)
- Operation
- Boulders
- Observation conditions for four instruments

5. Selection of landing site candidates for MASCOT

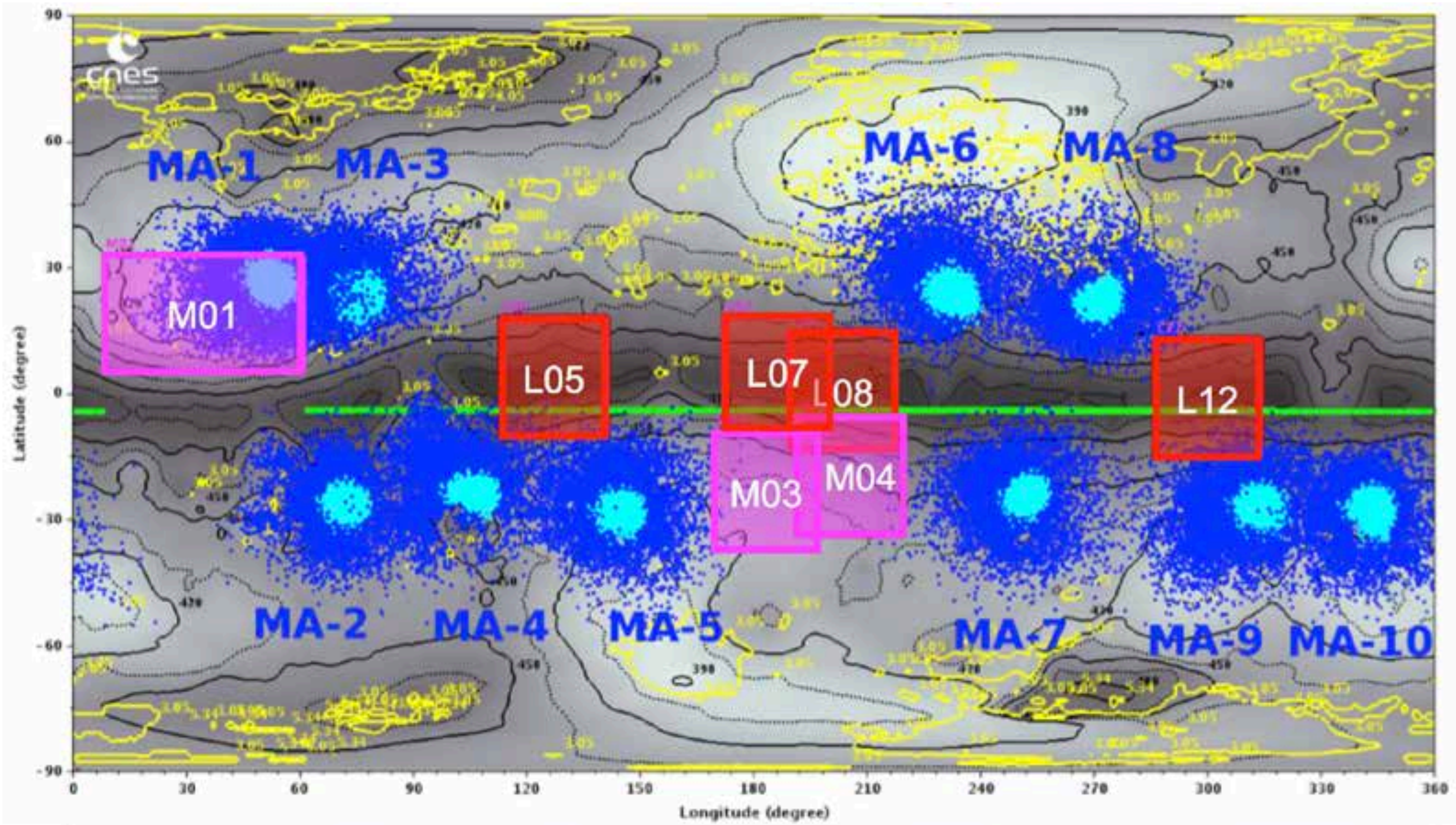
Scientific Criteria for Landing Site

Instrument	Criteria for Landing Site
MicrOmega	Composition of C-rich and/or OH-rich content. Low Temperature of landing site for high SNR (signal-to-noise ratio).
MASCAM	Boulders in the field of view Fine grained particles Compositional heterogeneity (color!) Fresh material (non-weathered)
MARA	Thin to no regolith layer. Landing or hopping close to boulders preferable. Preferentially less thermally altered region.
MASMAG	Low thermal inertia for fine grained fraction of the regolith Homogeneous thermal inertia (link the MARA + TIR data) Low rock abundance -> no inhomogeneities in the FoV (field of view)

Remote sensing instruments onboard HY2 give preliminary information on Ryugu : no big variation over the surface → homogenous

5. Selection of landing site candidates for MASCOT

Landing site candidates for MASCOT：selected 10 candidates (MA-1～MA-10)



（©DLR,CNES）

Light blue shows the first contact points and blue shows the first settlement points. The candidates of touchdown sites are shown by red squares (low latitude) and pink squares (mid- latitude).

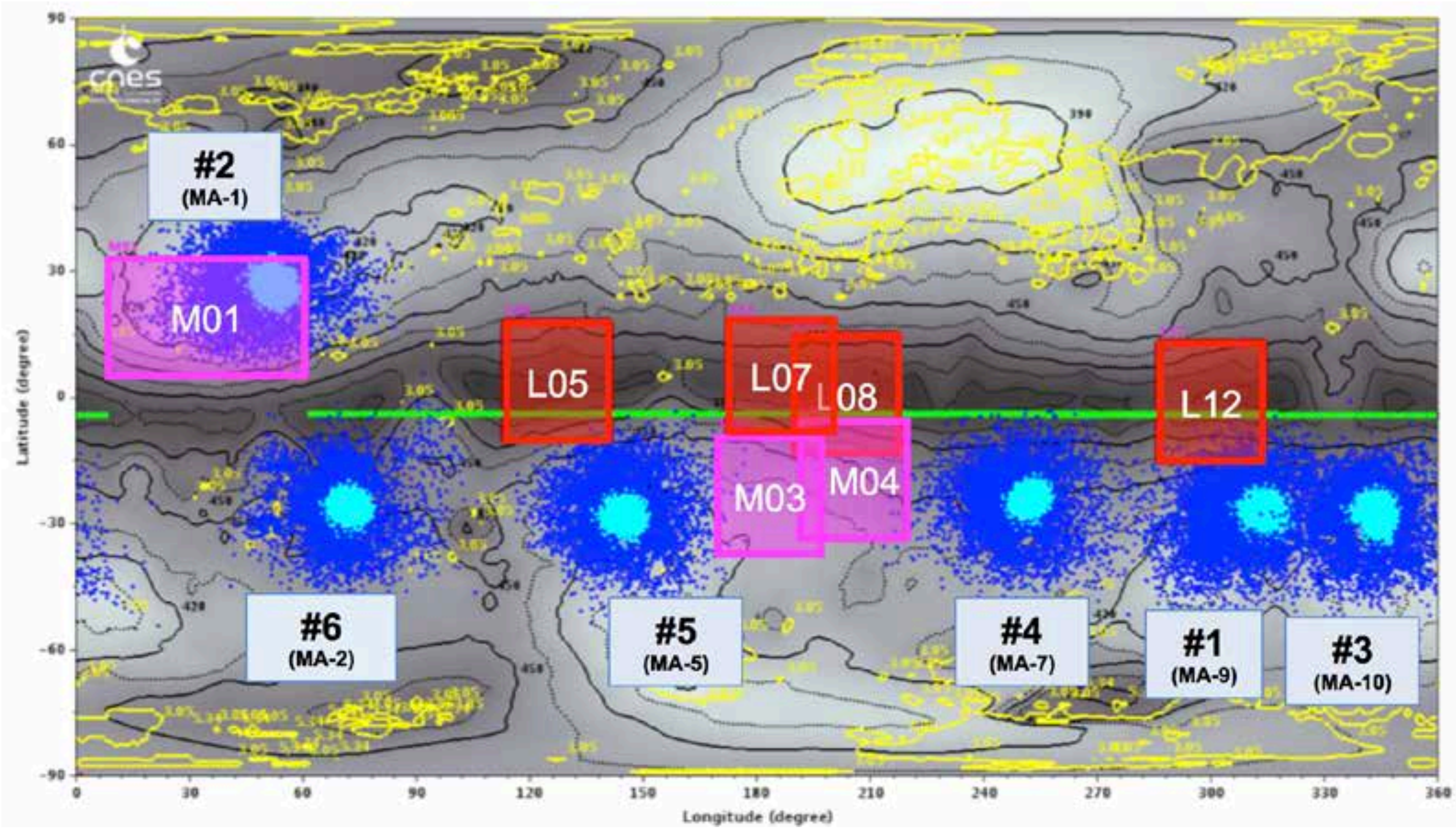
5. Selection of landing site candidates for MASCOT

MASCOT Ranking meeting (Toulouse Aug 14)

Fruitful meeting, useful rehearsal and training (thanks to JAXA)
=> complex process but all milestones/deliveries were reached according to the schedule

5. Selection of landing site candidates for MASCOT

Landing site candidates for MASCOT：Selection from 10 candidates and the order of priority

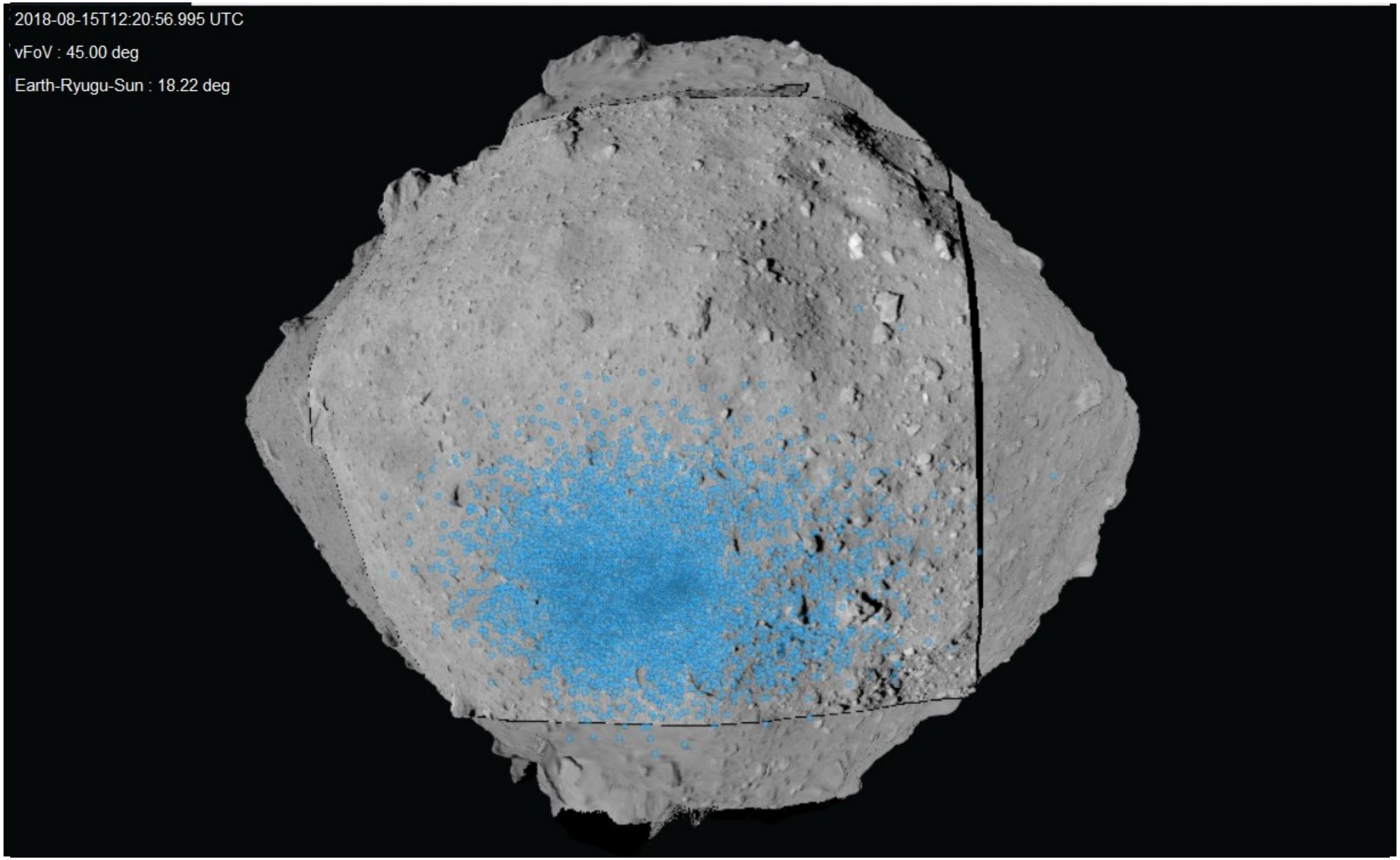


（©DLR,CNES）

Priority of landing site：MA-9 > MA-1 > MA-10 > MA-7 > MA-5 > MA-2

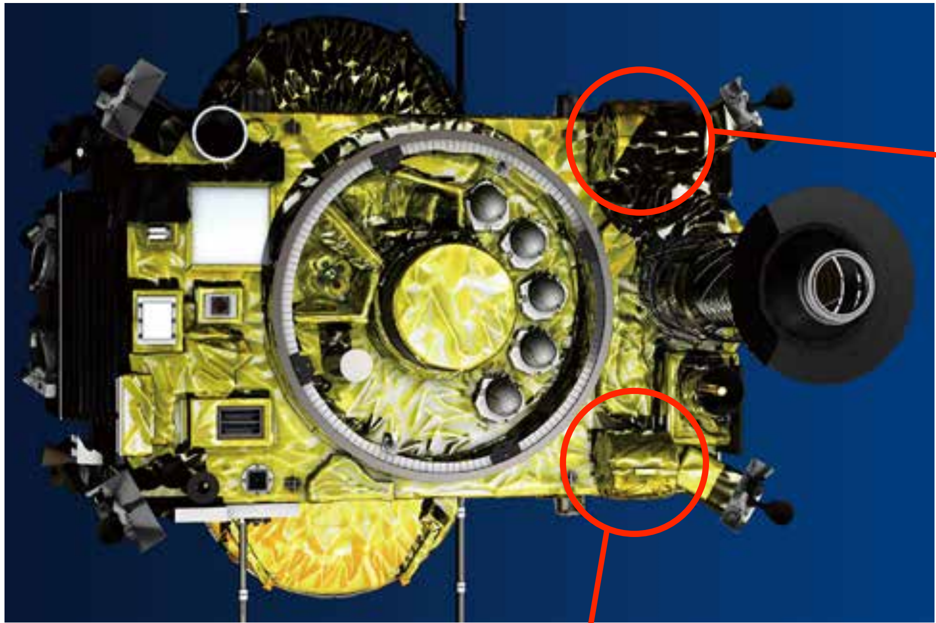
5. Selection of landing site candidates for MASCOT

MASCOT landing site

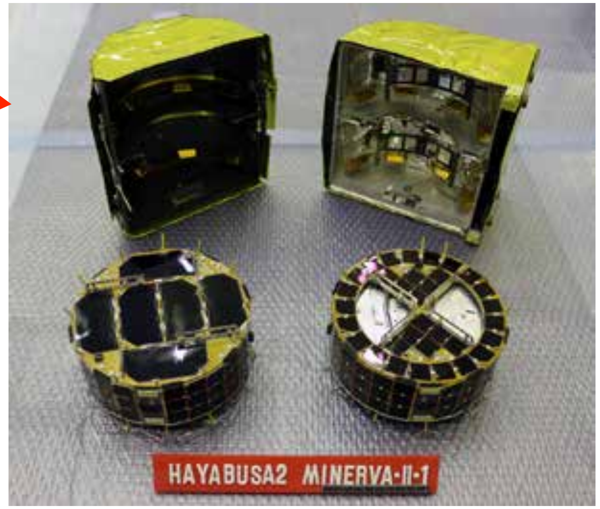


6. Selection of landing site candidates for MINERVA-II

Release of MINERVA-II-1 A & B（MINERVA-II-2 will be released next year）



MINERVA-II-1A, 1B



Produced at JAXA

MINERVA-II-2

Created by the MINERVA-II consortium (Tohoku University, Tokyo Denki University, Osaka University, Yamagata University, Tokyo University of Science)

<u>MINERVA-II-1A、MINERVA-II-1B Specification</u>

- size：diameter 17cm、height 7cm
- weight：about 1kg each
- Actuator：2 DC motors
- Mounted sensor：camera, photodiode, accelerometer、thermometer, gyro.
- Communication speed：32kbps（max）

6. Selection of landing site candidates for MINERVA-II

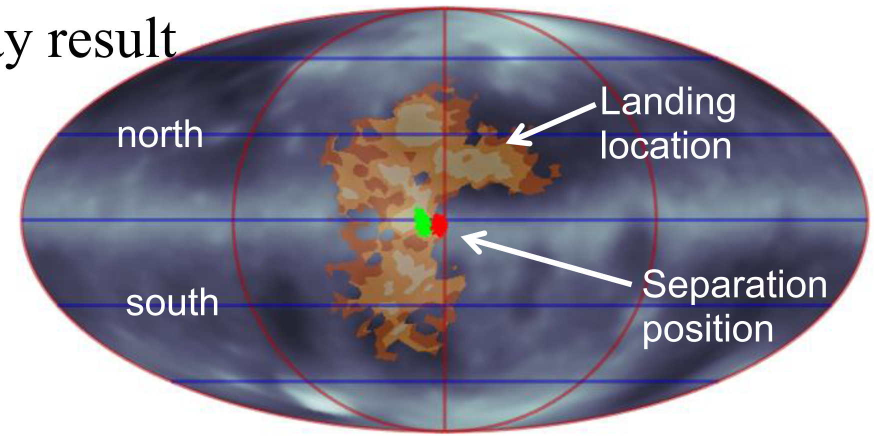
Conditions for MINERVA-II landing site selection：

- Landing site does not overlap with spacecraft touchdown candidates.
- Landing site does not overlap with MASCOT landing site candidates.
- The altitude of the spacecraft after separation must not be lower than 30m.
- Ensure communication with ground station.
- Not high temperature region, and fewer parts in shadow

▪Due to the equatorial ridge, separation near the equator results in widely spaced landing points to the north and south.

▪Separating in the southern hemisphere may result in a spacecraft altitude below 30m.

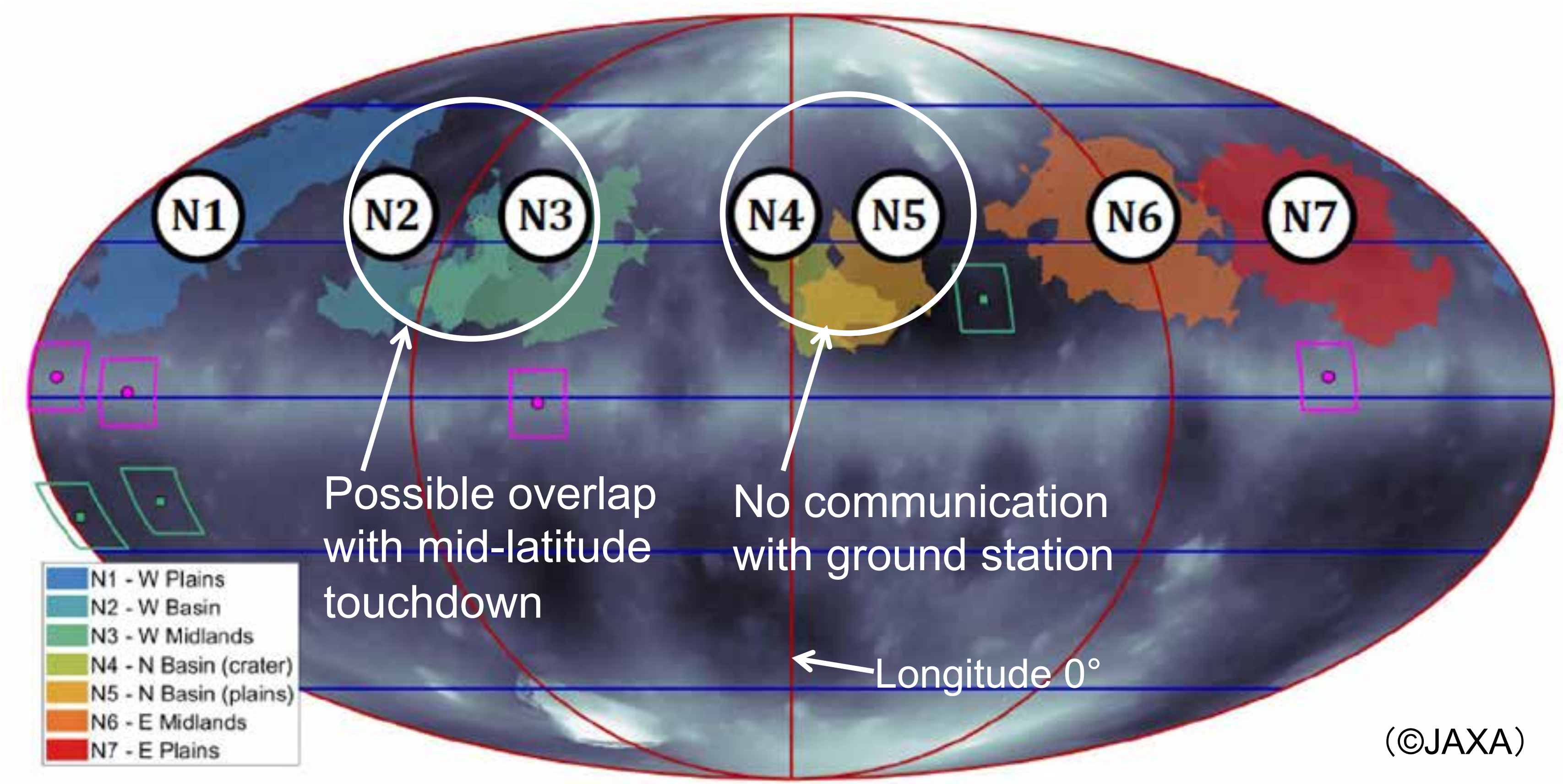
▪Separate in northern hemisphere, more than 100m north of the equator.



(©JAXA) When separating near the equator, the landing position spread north and south.

6. Selection of landing site candidates for MINERVA-II

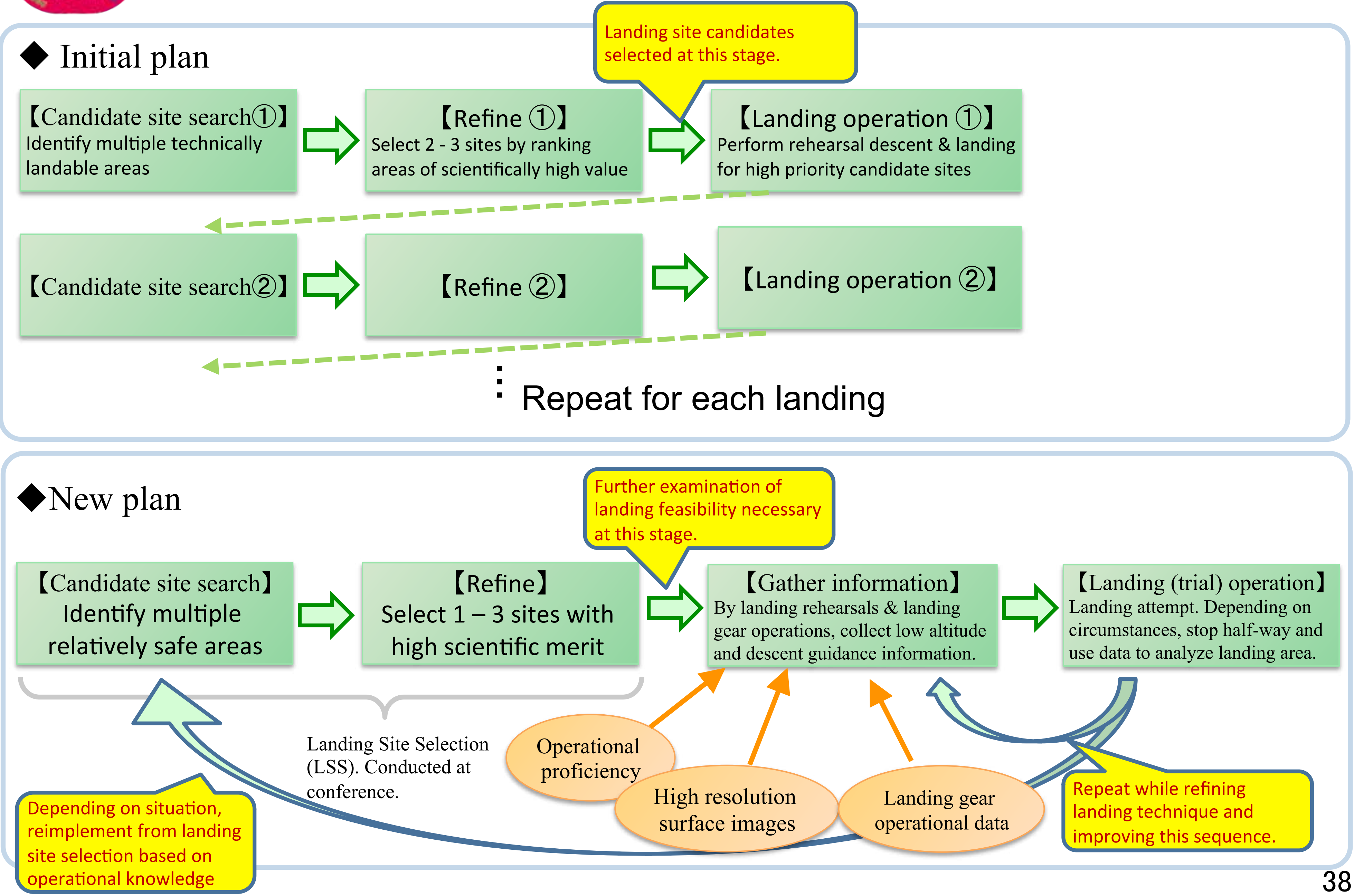
Landing site candidates for MINERVA-II: northern hemisphere



- Touchdown・confirm no overlap with MASCOT's landing site.
- Also consider observability etc. using the ONC-T camera.

Candidate locations：
N6 > N1 > N7

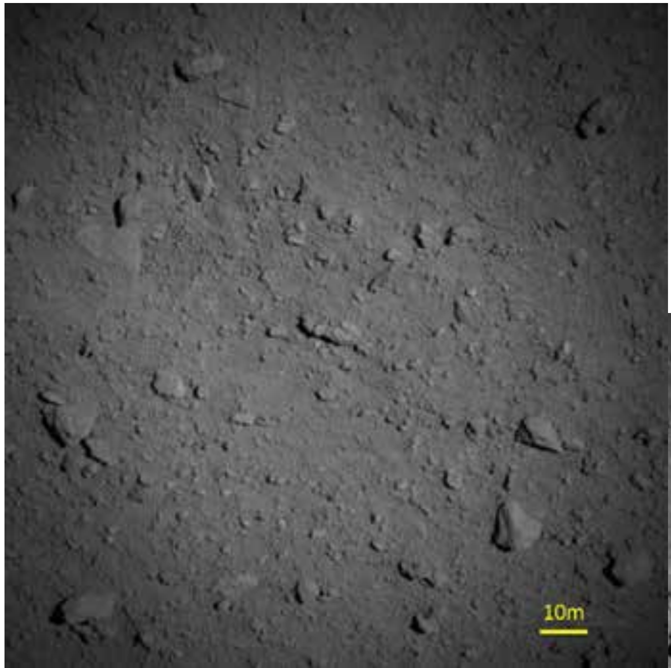
7. Strategy toward the successful touchdown

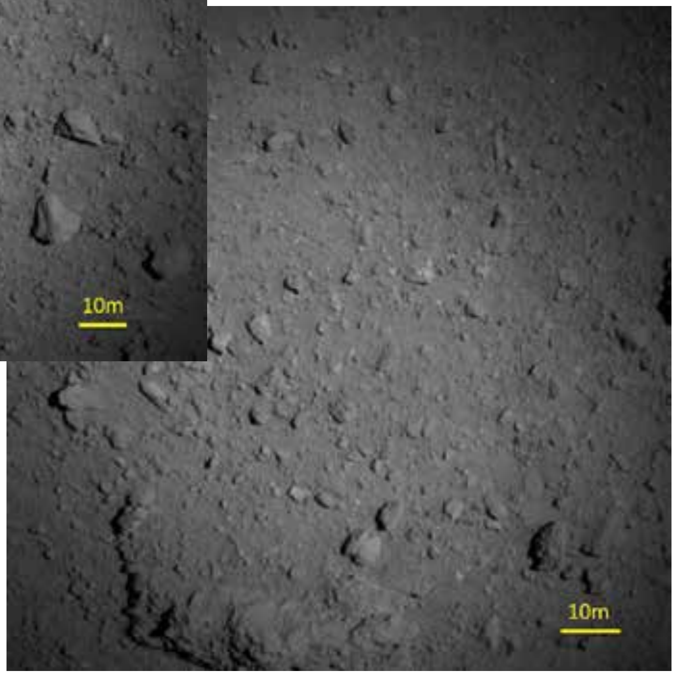


7. Strategy toward the successful touchdown

Important point

Detail of surface from low altitude





How far can the navigation guidance accuracy be increased?

Ryugu surface taken from an altitude of about 1km.

8. Future Plans

■Schedule for press briefings

- Sept. 5（Wed）11:00～12:00
- Sept. 27（Thurs）14:30～15:30

■Outreach and events (in Japanese)

➢ Events for Children

- Why Hayabusa2? Any questions classroom
- Sept. 2 (Sunday) 2 – 4pm
- Sagamihara City Museum
- Online broadcast planned

(Time : JST)