Hayabusa2 Mission Event Timeline Document

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Acronyms and Abbreviations

Acronym/Abbreviation	Definition
AOCS	Attitude and Orbit Control System
CCD	Charge-coupled device
DCAM3	Deployable Camera 3
Delta-DOR	Delta Differential One-way Ranging
DEM	Digital Elevation Map
DSN	Deep Space Network
EDVEGA	Electric Delta-V Earth Gravity Assist
ESA	European Space Agency
FF	Flat-Field
FLA	Flash Lamp
GCP	Ground Control Point
GCP-NAV	Ground Control Point Navigation
HK	House-Keeping
IES	Ion Engine System
LIDAR	Light Detection and Ranging
LRF	Laser Range Finder
MASCOT	Mobile Asteroid Surface Scout
MINERVA-II	MIcro Nano Experimental Robot Vehicle for Asteroid, the second generation
NIRS3	Near-Infrared Spectrometer
ONC	Optical Navigation Camera

Acronym/Abbreviation	Definition
OpNav	Optical Navigation
OWC	One Wheel Control
PPTD	Pin-Point Touch Down
RCS	Reaction Control System
ROI	Region Of Interest
SCI	Small Carry-on Impactor
SEP	Sun-Earth-Probe
SSOC	Sagamihara Space Operation Center
STT	Star Tracker
TCM	Trajectory Control Maneuver
TD	Touch Down
TI	Time Indicator
TIR	Thermal Infrared Imager
TM	Target Marker
TMT	Target Marker Tracking
UDSC	Usuda Deep Space Center
UTC	Coordinated Universal Time
XHGA	X-band High Gain Antenna
XLGA	X-band Low Gain Antenna
XMGA	X-band Medium Gain Antenna

1. Brief description of this document

This document provides definition of mission phases, brief description and event timeline of each mission phase and operation during the Asteroid Proximity phase.

2. List of Mission Phases

Start date/time in UTC, abbreviation, and name of mission phase are tabulated below.

Start date/time in UTC	Abbreviation	Name of mission phase
2014-12-03T04:22:04Z	commissioning	Commissioning phase
2015-03-03T00:00:00Z	edvega	EDVEGA (Electric Delta-V Earth Gravity Assist) phase
2015-10-01T00:00:00Z	earth_swing-by	Earth Swing-by phase
2015-12-22T14:10:00Z	transfer	Transfer phase
2018-06-03T05:59:00Z	approach	Approach phase
2018-06-27T00:35:00Z	proximity	Asteroid Proximity phase
2019-11-13T01:00:00Z	return	Return phase

3. Brief description of each mission phase

3.1. Commissioning phase

- Period: 2014-12-03T04:22:04Z – 2015-03-03T00:00:00Z
- Description: In this phase, critical operation and initial function check were conducted. In the several days after the launch, items shown below were conducted and/or confirmed.
  - ✓ Solar array panel deployment
  - ✓ Attitude control for solar array paddles' Sun acquisition
  - ✓ Sampling horn extension
  - ✓ Release of launch lock on the retaining mechanism for the gimbal that controls ion engine direction
  - ✓ Confirmation of spacecraft tri-axial attitude control functions
  - ✓ Ground-based confirmation of functions for precise trajectory determination system
  - ✓ Initial checkout of each subsystem
  - ✓ Turn on Ion Engine System
  - ✓ Test of solar sail mode that means attitude control utilizing solar radiation pressure

Event Timeline:

Date/Time in UTC	Event
2014-12-03T04:22:04	Launch from Tanegashima Space Center by H-IIA Launch Vehicle No. 26
2014-12-03T06:09:25	Separation of the Hayabusa2 spacecraft
2014-12-03T15:31:34	Observation of the Moon by ONC-W2
2014-12-07 – 08	Measurement of XMGA beam pattern, acquisition of data in space, and function test of X-band communication equipment
2014-12-09	Function check of power system
2014-12-10	Initial checkout of NIRS3 at normal temperature
2014-12-11	Initial checkout of ONC-T, ONC-W1, and ONC-W2 including sensitivity check using FF (Flat-Field) lamp
2014-12-11	Observation of stars by ONC-W2 (Algieba/Gamma Leonis, Regulus/Alpha Leonis, Castor/Alpha Geminorum, Alphard/Alpha Hydrae, and Gomeisa/Beta Canis Minoris)
2014-12-11	Observation of stars by ONC-T (22 stars, see Table 7 in Suzuki+2018)
2014-12-11	Function check of TIR
2014-12-11	Inspection of DCAM3
2014-12-12 – 15	Function check of AOCS
2014-12-16	Inspection of MINERVA-II and MASCOT
2014-12-17	Initial checkout of re-entry capsule and SCI
2014-12-17	Performance test of TIR and tuning temperature #1
2014-12-18	XHGA five-spot pointing test, and preparation of ion engine operation
2014-12-18	Acquisition of ONC-W2 image with stray light
2014-12-19	Tuning of IES accumulator pressure
2014-12-19 – 20	IES 24-hour baking by heaters
2014-12-22	Thruster grid baking by plasma ignition
2014-12-23	Ion engine aging and checkout, ion engine A
2014-12-24	Ion engine aging and checkout, ion engine B
2014-12-25	Ion engine aging and checkout, ion engine C
2014-12-26	Ion engine aging and checkout, ion engine D
2014-12-27 – 2015-01-04	Precise orbit determination and Delta-DOR operation

Date/Time in UTC	Event
2015-01-05 – 07	Data acquisition of Ka-band communication equipment, and measurement of its antenna pattern (five-spot pointing test)
2015-01-09 – 10	Delta-DOR by each Ka-band DSN station, and ranging tests
2015-01-11	Preparation for IES operation
2015-01-12	Two ion engines combination test, A and C
2015-01-13	Two ion engines combination test, C and D
2015-01-14	Two ion engines combination test, A and D
2015-01-15	Two ion engines combination test, A and C
2015-01-16	Three ion engines combination test, A, C, and D
2015-01-19 – 20	Two ion engines combination test, A and D, for 24-hour continuous autonomous operation
2015-01-20 – 2015-03-02	Functional confirmation to move to the next phase including combined, cooperative operation with multiple instruments; evaluation of solar radiation pressure effects; data acquisition of sun tracking behavior; combined operational function confirmation on solar radiation pressure, AOCS, and IES
2015-01-23	Function check of LIDAR, LRF, and FLA
2015-01-29	Tuning temperature of TIR #2
2015-02-19	Observation of stars by ONC-W1 (Regulus/Alpha Leonis, Alphard/Alpha Hydrae, Pollux/Beta Geminorum, and Procyon/Alpha Canis Minoris)
2015-02-19	Measurement of mounting alignment of ONC-W1 and ONC-W2 using Jupiter
2015-02-23	Initial checkout of NIRS3 at low temperature
2015-02-26	Observation of Jupiter by ONC-W1 and ONC-W2
2015-02-27	Tuning temperature of TIR #3

Note that blue-colored rows are the events related to scientific observation.

3.2. EDVEGA (Electric Delta-V Earth Gravity Assist) phase

- Period: 2015-03-03T00:00:00Z – 2015-10-01T00:00:00Z
- Description: In this phase, the spacecraft was driven by IES to enter the Earth Swing-by corridor. This phase is designed as follows:
  - ✓ To enlarge an operational margin on the IES, i.e., this phase has long non-driving period of IES.
  - ✓ To separate launch constraints and asteroid reachability constraints.
  - ✓ To provide backup windows.

Event Timeline:

Date/Time in UTC	Event
2015-03-03 – 21	EDVEGA phase #1, IES A and D, 409 hours, delta-V is 44 m/s
2015-03-26 – 2015-05-07	Solar sail mode (One Wheel Control) operation
2015-04-09	Acquisition of dark data for calibration of NIRS3 data
2015-04-10	Tuning temperature of TIR #4
2015-04-16	Observation of Jupiter by ONC-W2 and health check of ONC including sensitivity test using FF lamp
2015-04-28	Tuning temperature of TIR #5
2015-04-30 – 2015-05-01	Acquisition of dark data for calibration of NIRS3 data
2015-05-09	Health check of ONC-W1, ONC-W2, and ONC-T
2015-05-12 – 13	IES 24-hour autopilot operation with three thrusters (IES A, C, and D, 24 hours, delta-V is 4 m/s)
2015-05-30	Acquisition of dark data for star observation by NIRS3
2015-06-01	Observation of stars (Arcturus/Alpha Boötis) by NIRS3 and measurement of mounting alignment of NIRS3 (no signal)
2015-06-01	Observation of stars by ONC-W2 and ONC-T
2015-06-02 – 06	EDVEGA phase #2, IES A and D, 102 hours, delta-V is 11 m/s
2015-06-09 – 2015-09-01	Solar sail mode operation
2015-06-11	Tuning temperature of TIR #6
2015-06-23	Observation of Saturn by ONC-W1 and ONC-T
2015-06-25	Acquisition of dark data for calibration of NIRS3 data
2015-06-30	Acquisition of ONC-T images with stray light by the ONC-T radiator
2015-07-16	Tuning temperature of TIR #7
2015-09-01 – 02	EDVEGA phase #3, IES A and D, 12 hours, delta-V is 1.3 m/s, also known as IES-TCM
2015-09-03	Tuning temperature of TIR #8
2015-09-04	Acquisition of dark data for calibration of NIRS3 data
2015-09-10	Health check of ONC-W1, ONC-W2, and ONC-T including sensitivity test using FF lamp
2015-09-18	Closest approach to the Sun during nominal mission (0.91 AU)

Note that blue-colored rows are the events related to scientific observation.

3.3. Earth Swing-by phase

- Period: 2015-10-01T00:00:00Z – 2015-12-22T14:10:00Z
- Description:
  - In this phase, the spacecraft will acquire delta-V by the Earth swing-by.
  - Observation of Earth and the Moon for calibration of instruments, ONC, TIR, and NIRS3.
  - LIDAR laser link experiment between the spacecraft and Earth

Event Timeline:

Date/Time in UTC	Event
2015-10-12 – 16	Observation of Earth and the Moon by ONC-W1 and ONC-T
2015-10-13 – 15	LIDAR laser link experiment
2015-10-14, 16	Observation of Earth and the Moon by TIR, first light from Earth and the Moon
2015-10-15	Observation of Earth by NIRS3 and measurement of mounting alignment of NIRS3 (first light from Earth)
2015-10-17	Acquisition of ONC-T images with stray light by the ONC-T radiator
2015-11-03T04:00 – 06:00	TCM1 for Earth swing-by using RCS thrusters, delta-V is 0.229 m/s
2015-11-04 – 25	Precise orbit determination for the Earth swing-by
2015-11-05	Changed observation program for TIR
2015-11-05	Acquisition of ONC-T images with stray light by the ONC-T radiator
2015-11-09	Observation of Earth and the Moon by ONC-W1 and ONC-T
2015-11-09	Acquisition of ONC-T images with stray light by the ONC-T radiator
2015-11-10 – 12	Observation of Earth by NIRS3 and measurement of its mounting alignment
2015-11-10 – 13	Observation of Earth and the Moon by TIR
2015-11-10 – 14	LIDAR laser link experiment
2015-11-13 – 14	Observation of Earth and the Moon by ONC-W1 and ONC-T
2015-11-25T23:30 – 2015-11-26T02:00	TCM2 for Earth swing-by using RCS thrusters, delta-V is 0.047 m/s
2015-11-25 – 26	Observation of Earth and the Moon by NIRS3
2015-11-26	Observation of Earth and the Moon by ONC-W1, ONC-T, and TIR
2015-11-27	Precise orbit determination
2015-12-01	TCM3 for Earth swing-by was originally planned, but was canceled

Date/Time in UTC	Event
2015-12-01 – 03	Precise orbit determination just before the Earth swing-by
2015-12-03	Observation of Earth by ONC-W2
2015-12-03T10:08:07	Closest approach to Earth, at 3090 km altitude above Hawaii, 1.6 km/s delta-V
2015-12-03 – 05	Observation of Earth and the Moon by NIRS3
2015-12-04	Observation of Earth by ONC-W1, ONC-T, and TIR
2015-12-04 – 08	Orbit determination after the Earth swing-by
2015-12-05	Observation of sodium atmosphere of Earth by ONC-T
2015-12-05	Observation of Earth and the Moon by ONC-W1 and ONC-T
2015-12-05 – 06	Observation of the Moon by TIR
2015-12-06 – 08	Observation of Earth and the Moon by ONC-W1
2015-12-06 – 08	Observation of Earth by ONC-T, TIR, and NIRS3
2015-12-08	Observation of airglow of Earth's atmosphere by ONC-T (no signal)
2015-12-09 – 21	Observation of Earth and the Moon by TIR
2015-12-11 – 21	LIDAR laser link experiment (successfully received laser at 6,600,000 km away from Earth on 2015-12-19)
2015-12-21	Observation of Earth by NIRS3 and measurement of its mounting alignment
2015-12-22T14:10:00	Changed Earth and the Moon pointing attitude to Sun-pointing attitude

Note that blue-colored rows are the events related to scientific observation.

3.4. Transfer phase

- Period: 2015-12-22T14:10:00Z – 2018-06-03T05:59:00Z
- Description: In this phase, the spacecraft was driven by IES and approached close enough to be able to use optical navigation for rendezvous with Ryugu.

Event Timeline:

Date/Time in UTC	Event
2015-12-22	Acquisition of ONC-T images with stray light by the ONC-T radiator
2015-12-22	Observation of Earth and the Moon by ONC-W1
2015-12-25	Observation of Earth and the Moon by ONC-W1
2016-01-11 – 2016-03-18	Solar sail mode operation
2016-02-04	Tuning temperature of TIR #9

Date/Time in UTC	Event
2016-02-09 – 2016-03-21	Observation of stars (Achernar, Canopus, Procyon, Rigel, Sirius, Alpha Centauri A and B) by ONC-W2 to investigate sensitivity
2016-02-09 – 2016-03-21	Observation of Jupiter by ONC-W1 to investigate sensitivity
2016-02-09 – 2016-03-21	Acquisition of ONC-T images with stray light by the ONC-T radiator
2016-02-19	Acquisition of dark data for calibration of NIRS3 data
2016-03-03	Tuning temperature of TIR #10
2016-03-22T13:55 – 2016-05-05T01:27	Transfer phase #1, IES A, C, and D. Total operating time of IES is about 795 hours, delta-V is 127 m/s
2016-05-11	Tuning temperature of TIR #11
2016-05-20T13:00 – 15:39	Transfer phase #1, IES trim maneuver, IES A, and D, 3.6 hours, delta-V is about 40 cm/s
2016-05-24	Changed attitude for Mars observation (-Z direction points to Mars)
2016-05-24	Observation of Mars by NIRS3
2016-05-24 – 25	Observation of Mars by ONC-T
2016-05-31	Observation of Mars by ONC-T, ONC-W1 and NIRS3 and acquisition of dark data for calibration of NIRS3 data
2016-06-02 – 08	Observation of Mars by NIRS3
2016-06-02 – 09	Observation of Mars by ONC-T (02 – 03, 05 – 09)
2016-06-07	Observation of Mars by ONC-W1
2016-06-09	Observation of Mars by TIR (no signal recorded because of too low thermal emission, as supposed)
2016-06-14 – 20	Measurements of torque generated by solar radiation pressure
2016-06-22 – 23	DSN-DSN uplink transfer test
2016-06-25	Health check of SCI
2016-06-28 – 2016-07-02	Observation of stars by ONC-W2 to investigate sensitivity, and observation of Jupiter by ONC-W1 to investigate sensitivity (28, 30, 02)
2016-06-28 – 2016-07-23	Acquisition of ONC-T images with stray light by the ONC-T radiator (28, 30, 02, 05, 08, 11, 15, 17, 23)
2016-06-29 – 2016-07-03	DSN station Ka communication test and Delta-DOR test
2016-07-05 – 08	ESA station Ka compatibility test
2016-07-14 – 16	Functional test for MASCOT operation

Date/Time in UTC	Event
2016-07-15	Tuning temperature of TIR #12
2016-07-19	Functional test of LIDAR with changed parameters
2016-07-26	Test performance of RCS
2016-08-02 – 2016-10-22	Acquisition of ONC-T images with stray light by the ONC-T radiator (2016-08-02 – 05, 07, 09, 12, 17, 22, 2016-09-20, 2016-10-04, 19, 20, 22)
2016-08-03 – 2016-10-08	Solar sail mode operation
2016-08-25	Acquisition of dark data for calibration of NIRS3 data
2016-10-11, 16	Observation of Mars by STT-A (Star Tracker A)
2016-10-16 – 22	Observation of star (Homam/Zeta Pegasi) by ONC-T (16, 19 – 22)
2016-10-25	Simulated observation by TIR
2016-11-02, 04	DSN-UDSC uplink transfer test
2016-11-13	Simulated observation by TIR
2016-11-22 – 2017-04-25	Transfer phase #2, IES A, C, and D
2016-12-27 – 28	Acquisition of dark current data of ONC-T to investigate temperature dependence
2017-01-03	Simulated observation by TIR
2017-03-11	Passed perihelion
2017-03-12	Observation of stars (Betelgeuse/Alpha Orionis, Capella/Alpha Aurigae, Procyon/Alpha Canis Minoris) for investigation of ONC-W1 image distortion
2017-04-17	Simulated observation by TIR using Sun-Earth L5 point
2017-04-17	Deep sky observation with variation of CCD and electric circuit temperatures of ONC
2017-04-17 – 18	Observation of the Sun-Earth L5 point by ONC-T (no moving objects found)
2017-04-18	Acquisition of deep space data with and without calibration lamps for calibration of NIRS3 data
2017-04-25 – 26	Transfer phase #2, IES trim maneuver, IES A and D
2017-04-28	Test of binning function for ONC
2017-05-09 – 12	MASCOT health check
2017-05-16	Observation of Jupiter by NIRS3 and acquisition of dark data for calibration of NIRS3 data
2017-05-16 – 17	Observation of Jupiter by ONC-T

Date/Time in UTC	Event
2017-05-18 – 20	Simulated observation by TIR
2017-05-18 – 20	Observation of Jupiter and Jupiter's sodium cloud by ONC-T (no significant signal for the cloud)
2017-05-23	Observation of Jupiter by NIRS3 and acquisition of dark data for calibration of NIRS3 data
2017-05-23, 25	Observation of star by ONC-T for acquisition of flat field data with variation of CCD and electric circuit temperatures
2017-05-23 – 28	Observation of star (Theta Crateris) by ONC-T
2017-05-30 – 2017-06-01	RCS autonomous maneuver test
2017-06-13 – 20	Acquisition of ONC-T images with stray light by the ONC-T radiator (13, 15, 18, 20)
2017-06-13 – 20	Observation of Jupiter by ONC-W1 and observation of sky by ONC-W2 (13, 15, 18, 20)
2017-07-08	Health check of ONC-W1, ONC-W2, and ONC-T including sensitivity test using FF lamp
2017-07-18 – 23	MASCOT software update and testing
2017-07-18 – 2017-11-14	Updates of program of instruments
2017-08-17	Simulated observation by TIR
2017-08-29	Changed attitude to Sun pointing
2017-08-29	Acquisition of ONC data with stray light for observation during SCI operation #1
2017-09-05	Reset TI of spacecraft manually
2017-10-04	Acquisition of dark data for calibration of NIRS3 data
2017-10-10	Observation of stars (Albali/Epsilon Aquarii and Mu Aquarii) by ONC-T
2017-10-12 – 14	Observation of stars (Nunki/Sigma Sagittarii, Ascella/Zeta Sagittarii, Phi Sagittarii, and Tau Sagittarii) by ONC-T
2017-10-15	Acquisition of ONC-T dark image to investigate temperature dependence
2017-10-16	Health check of ONC-W1, ONC-W2, and ONC-T including sensitivity test using FF lamp
2017-10-17 – 21	Acquisition of ONC-T image with stray light by the ONC-T radiator and ONC-W1 and ONC-W2 images for observation during SCI operation #2 (17, 19, 21)
2017-10-24	Test of observation program for TIR

Date/Time in UTC	Event
2017-11-03	Observation of Saturn by ONC-T
2017-11-16	Test of ROI (Region Of Interest) function using ONC-T
2017-11-18	DSN-SSOC real time Doppler transfer test
2017-11-28	DSN-SSOC real time Doppler transfer test
2017-11-29	Simulated observation by TIR
2017-11-30, 2017-12-02	Acquisition of dark image of ONC-W1 and ONC-W2 to investigate temperature dependence
2017-12-02	DSN-UDSC uplink transfer test
2017-12-02	Observation of stars by ONC-W1 and ONC-W2
2017-12-05	Acquisition of ONC-T images to investigate linearity using FF lamp with variation of exposure time
2017-12-16	Acquisition of dark data for calibration of NIRS3 data
2017-12-16	Simulated observation by TIR
2017-12-26 – 27	IES test maneuver; 5 hours total using two engines at the same time
2018-01-10	Transfer phase #3, IES A and D
2018-02-20T02:56	Transfer phase #3, changed number of engines from two to three (A, C, D)
2018-02-26	Ryugu first light by ONC-T (1.3 million km away from Ryugu)
2018-04-30	Health check of ONC-W1, ONC-W2, and ONC-T and acquisition of dark data of ONC to investigate temperature dependence
2018-05-07	Acquisition of dark data of ONC-T to investigate temperature dependence and acquisition of data of ONC-W1 and ONC-W2 for sensitivity investigation
2018-05-11 – 14	OpNav (Optical Navigation) Phase #1; using acquired images by STT, 78000 km away from Ryugu)
2018-06-03T05:59	Transfer phase #3 was ended; total delta-V of Transfer phase #3 is 393 m/s, 2475 hours

Note that blue-colored rows are the events related to scientific observation.

3.5. Approach phase

- Period: 2018-06-03T05:59:00Z – 2018-06-27T00:35:00Z
- Description:
  - Approach to Ryugu using RCS thrusters and optical navigation (hybrid navigation using optical and radiometric observations).

- Observation of Ryugu by ONC-T to search for satellites (not found) for safety of the spacecraft.

Event Timeline:

Date/Time in UTC	Event
2018-06-03T05:59	Start of asteroid approach, 3100 km away from Ryugu
2018-06-05 – 27	Observation for optical navigation by ONC-T
2018-06-05 – 06	Observation for searching satellite by ONC-T
2018-06-06	Ryugu first light by TIR
2018-06-08T03:30 – 04:40	TCM01 (Trajectory Correction Maneuver #01), 1900 km away from Ryugu. The relative velocity is about 2.35 m/s
2018-06-11T00:30 – 01:40	TCM02,1320 km away from Ryugu. The relative velocity is about 2.1 m/s
2018-06-13 – 16	Observation for searching satellite by ONC-T (13, 15, 16)
2018-06-14T03:40 – 04:50	TCM03, 750 km away from Ryugu. The relative velocity is about 1.7 m/s
2018-06-16T00:30 – 01:40	TCM04, 470 km away from Ryugu. The relative velocity is about 1.3 m/s
2018-06-18T02:00 – 03:10	TCM05, 220 km away from Ryugu. The relative velocity is about 0.7 m/s
2018-06-18, 20	Observation of sodium atmosphere of Ryugu by ONC-T
2018-06-20T03:40 – 04:50	TCM06, 110 km away from Ryugu. The relative velocity is about 0.4 m/s
2018-06-20	Stepped into the Hill sphere of Ryugu. About 90 km away from Ryugu
2018-06-21	Ryugu first light by NIRS3
2018-06-22T00:30 – 01:40	TCM07, 45 km away from Ryugu. The relative velocity is about 0.09 m/s
2018-06-24T00:30 – 00:40	TCM08, 38 km away from Ryugu. The relative velocity is about 0.08 m/s
2018-06-26T01:10 – 01:20	TCM09, 23 km away from Ryugu. The relative velocity is about 0.02 m/s
2018-06-27T00:30 – 00:35	TCM10, 20.7 km away from Ryugu. The relative velocity is less than about 0.01 m/s

Note that blue-colored rows are the events related to scientific observation.

3.6. Asteroid Proximity phase

- Period: 2018-06-27T00:35:00Z – 2019-11-13T01:00:00Z
- Description: Purposes of operations during this phase are as follows:
  - Observe Ryugu by remote sensing and collecting information for landing site selection.
  - Touch down to Ryugu and collecting samples of Ryugu.
  - Create artificial crater by impactor.

- Touch down to Ryugu near the impact point and collecting samples under the surface of Ryugu after impact experiment.
- Deployments of the MINERVA-II rovers and the MASCOT lander for in-situ observations.

Event Timeline:

Date/Time in UTC	Event
2018-06-27T00:35:00	Arrived at the home position of Ryugu, 20.7 km altitude
2018-07-17 – 25	BOX-C operation (BOX-C-1)
2018-07-31 – 2018-08-02	Mid-altitude descent observation (MID)
2018-08-04 – 07	Gravity measurement descent operation (GRV)
2018-08-18 – 2018-09-07	BOX-B operation (BOX-B1 and BOX-B-2)
2018-09-10 – 12	Touch-down #1 Rehearsal 1 (TD1-R1)
2018-09-19 – 21	MINERVA-II1 deployment operation (MNRV1)
2018-10-01 – 04	MASCOT deployment operation (MSC)
2018-10-13 – 15	Touch-Down #1 Rehearsal 1A (TD1-R1-A)
2018-10-23 – 25	Touch-Down #1 Rehearsal 3 (TD1-R3)
2018-10-27 – 2018-11-05	BOX-C operation (BOX-C-2 and BOX-C-3)
2018-11-23 – 2018-12-29	Conjunction Orbit Operation
2019-01-06 – 13	BOX-B operation (BOX-B-3)
2019-01-19 – 31	BOX-B operation (BOX-B-4)
2019-02-19 – 22	Touch Down #1 (TD1-L08E1)
2019-02-23 – 2019-03-01	BOX-C operation (BOX-C-4)
2019-03-05 – 08	Low Altitude Descent Observation (DO-S01)
2019-03-19 – 21	Crater search descent pre-impact operation (CRA1)
2019-04-02 – 05	Small Carry-on Impactor operation (SCI)
2019-04-22 – 25	Crater search descent post-impact operation (CRA2)
2019-05-13 – 17	Pin-point Touchdown Rehearsal 1 (PPTD-TM1)
2019-05-28 – 30	Pin-point Touchdown Rehearsal 1A (PPTD-TM1A)
2019-06-10 – 13	Pin-point Touchdown Rehearsal 1B (PPTD-TM1B)
2019-07-08 – 12	Pin-point Touchdown operation (PPTD)
2019-07-20 – 31	BOX-C operation (BOX-C-5)
2019-08-08 – 14	BOX-B operation (BOX-B-5)

Date/Time in UTC	Event
2019-08-14 – 27	BOX-B operation (BOX-B-6)
2019-08-29 – 2019-09-11	Recovery from spacecraft anomaly on 2019-08-29
2019-09-11 – 22	Target Markers orbiting operation (TM-ORB)
2019-09-23 – 27	BOX-B operation (BOX-B-7)
2019-09-27 – 2019-10-02	MINERVA-II2 orbiting operation (MNRV-ORB)
2019-10-08 – 14	BOX-C operation (BOX-C-6)
2019-10-19 – 30	BOX-C operation (BOX-C-7)

Note that description of BOX-A, BOX-B, and BOX-C are provided in the section 4.1, and also note that BOX-A operation is regular operation, so BOX-A operations are not explicitly appeared in the event timeline above.

3.7. Return Phase

- Period: 2019-11-13T01:00:00Z –
- Description:
  - Return to Earth, carry samples of Ryugu in sample container, and separate sample container to join re-entry orbit.

Event Timeline:

Date/Time in UTC	Event
2019-11-13T01:00:00	Departure from Ryugu. Performed a small ascent delta-V, and will step out of the Hill's sphere of Ryugu about 5 days later
2019-11-13 – 19	"Good-bye Ryugu" campaign, observation of Ryugu by ONC-W1 and ONC-T
2019-11-20 – 28	Test drive of IES; combinations of (A, C, D), (A, C), (A, D), (C, D), (A), (C), (D)
2019-12-03	IES operation for the Return phase #1: start; using A, C, and D
2019-12-10	IES operation for the Return phase #1: using A, D
2020-02-03	IES operation for the Return phase #1: stop
2020-02-04	Test drive of IES B
2020-02-18 – 20	IES operation for the Return phase #1: trim drive using C
2020-02-20	IES operation for the Return phase #1: stop; total delta-V is 100 m/s, 881 hours
2020-02-27	Test observation by ONC-W1, ONC-W2, and ONC-T associated with turn ONC's power on
2020-05-11T22:00:00	IES operation for the Return phase #2: start; using C

Date/Time in UTC	Event
2020-08-04T15:00:00	IES operation for the Return phase #2: using C and D
2020-08-28T08:33	IES operation for the Return phase #2: stop
2020-08-31	RCS test maneuver (for TCM 3 simulation)
2020-09-15T14:00:00 – 2020-09-16T18:15:45	IES operation for the Return phase #2, trim maneuver (TCM-0): using C
2020-10-22T09 – 10	TCM-1; total delta-V will be about 15 cm/s
2020-11-12T06:45 – 07:45	TCM-2; total delta-V will be about 1 cm/s
2020-11-25T07 – 08	TCM-3; total delta-V will be about 1.2 m/s
2020-12-01T07	TCM-4; total delta-V will be about 4.6 cm/s
2020-12-05T05:30	Separation of the sample return capsule
2020-12-05T07:30 – 08:30	TCM-5; performed three delta-V maneuvers
2020-12-05T17:54	landing of the capsule

Note that blue-colored rows are the events related to scientific observation.

4. Operations during Asteroid Proximity Phase

4.1. Note on BOX-A, BOX-B, and BOX-C operations

The spacecraft keeps a nominal position at 20 km altitude from Ryugu which is called Home Position during the Asteroid Proximity phase. There are three kinds of operations called BOX-A, BOX-B, and BOX-C operations, which are operations for scientific observation moving inside of rectangular regions. Figure 1 shows a schematic diagram of regions used for BOX-A, BOX-B, and BOX-C operations.

- BOX-A: This operation is for nominal observation at around the home position, about 20 km altitude of Ryugu. Sizes of the box is about 1 km in x-, y-, and z-directions.
- BOX-B: This operation is designed for observation from different angles, i.e., the north pole direction, the south pole direction, the dawn direction, and the dusk direction.
- BOX-C: This operation is a non-critical descent observation with about 5 km of minimum altitude.

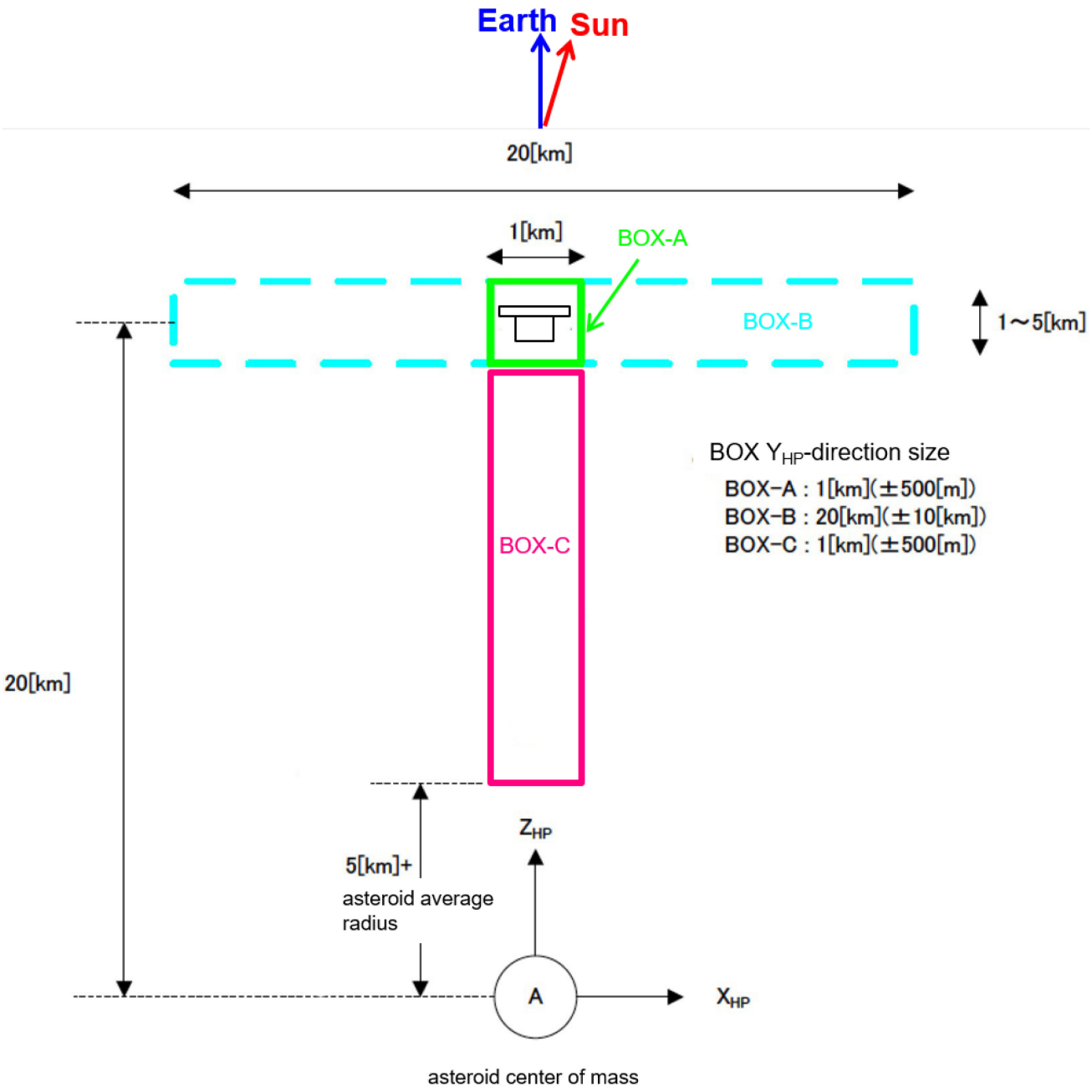

Figure 1 Schematic diagram of BOX-A, BOX-B, and BOX-C regions. These regions are defined in Home Position reference frame which is defined as two-vector dynamic reference frame using Sun and Earth position and the origin of the coordinate is the center of Ryugu. Credit: JAXA

4.2. BOX-C operation (BOX-C-1)

- Date: 2018-07-17 – 2018-07-25
- Description:
  - Descended to 6 km altitude on 2018-07-20 and observed Ryugu from about 6 km altitude.

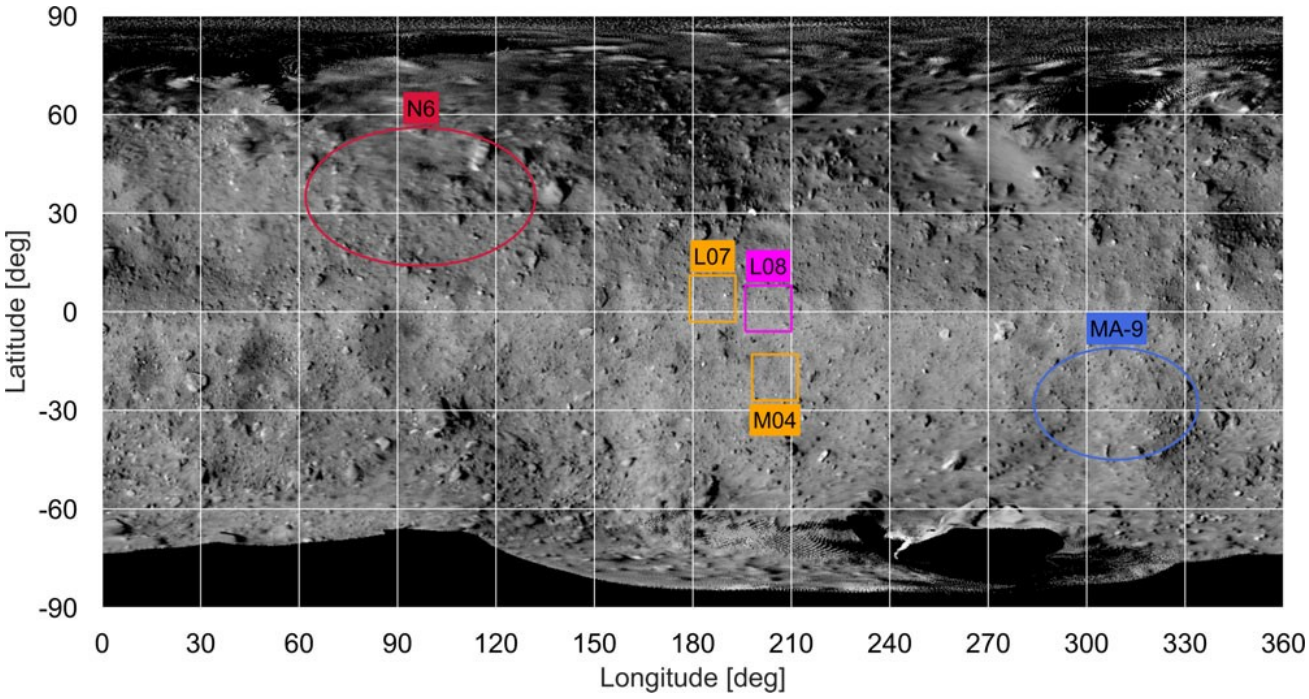

Figure 2 Map of Ryugu with candidate landing sites created from ONC-T images acquired during the BOX-C-1 operation. Credit: JAXA, Univ. of Tokyo, Kochi Univ., Rikkyo Univ., Nagoya Univ., Chiba Institute of Technology, Meiji Univ., Univ. of Aizu, AIST.

4.3. Mid-altitude descent observation (MID)

- Date: 2018-07-31 – 2018-08-02
- Description:
  - ➢ Primary purposes are as follows:
    - ✓ Observe latitudinal area during one rotation period that can be candidate of touch down site from 5 km altitude for scientific purpose.
    - ✓ Acquire images to create GCP (Ground Control Point) database used for GCP-NAV (Ground Control Point Navigation).
  - ➢ Results
    - ✓ Reached 5 km altitude and observed one rotation period of Ryugu successfully.
- Condition:
  - ➢ One-way light time between Earth and the spacecraft: about 975 seconds (= 16 min 15 sec)

Event Timeline:

Date/Time in UTC	Event
2018-07-31T00:30 (ground)	Started preparation for descent
2018-08-01T00:40 (ground)	Gate 1 decision (Descent start = Go)

Date/Time in UTC	Event
2018-08-01T01:10	Started descent, 20 km altitude, descent rate is -0.4 m/s
2018-08-01T11:00	Changed descent rate to 0 m/s, 5 km altitude
2018-08-01T11:21 (ground)	Gate 2 decision (Hovering readiness = Confirmed)
2018-08-01T12:48	Entered hovering guidance mode
2018-08-01T14:48	Started hovering observation
2018-08-01T22:29	Ascent delta-V, ascent rate is 0.24 m/s
2018-08-01T22:45 (ground)	Gate 4 decision (Observation completion & ascent = Confirmed)
2018-08-01T22:59 (ground)	Gate 6 decision (Home position return maneuver = Go)
2018-08-02T00:30	Home position return maneuver

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time. Note that blue-colored rows are the events related to scientific observation.

4.4. Gravity measurement descent operation (GRV)

- Date: 2018-08-04 – 2018-08-07
- Description:
  - Primary purposes are as follows:
    - ✓ Measure the gravity field of Ryugu with 1% accuracy, which is necessary for accurate descent to Ryugu.
  - Results
    - ✓ Successful measurement of the gravity field.
    - ✓ Reached 851 m altitude.
- Condition:
  - One-way light time between Earth and the spacecraft: about 980 seconds (= 16 min 20 sec)

Event Timeline:

Date/Time in UTC	Event
2018-08-04T23:30 (ground)	Started preparation for descent
2018-08-06T00:35 (ground)	Gate 1 decision (Descent start = Go)
2018-08-06T01:35	Started descent, 20 km altitude, descent rate is -0.4 m/s
2018-08-06T11:00	Changed descent rate to -0.1 m/s at 6.52 km altitude
2018-08-06T11:16 (ground)	Gate 2 decision (Free fall readiness = Go)

Date/Time in UTC	Event
2018-08-06T14:00	Trajectory Correction Maneuver (TCM) to enter free fall trajectory
2018-08-06T23:10	Lowest altitude, 851 m, ascent delta-V
2018-08-06T23:03 (ground)	Gate 4 decision (Ascent confirmation = Confirmed)
2018-08-07T07:42 (ground)	Gate 6 decision (Gravity measurement completion = Confirmed)
2018-08-07T08:50	Home position return delta-V

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time. Note that blue-colored rows are the events related to scientific observation.

4.5. BOX-B operation (BOX-B-1 and BOX-B-2)

- Date: 2018-08-18 – 2018-09-07
- Description:
  - Tour observation at 20 km altitude. Observation from south pole direction (BOX-B-1) and evening direction (BOX-B-2) of Ryugu.

4.6. Touch-down #1 Rehearsal 1 (TD1-R1)

- Date: 2018-09-10 – 2018-09-12
- Description:
  - Primary purposes are as follows:
    - ✓ Assess the feasibility of TD1 (Touch-Down #1) operation sequence.
    - ✓ Test and improve degree of skills with spacecraft operation of the operation members.
    - ✓ Assess thermal effect and characteristics of LRF at low altitude.
  - Results
    - ✓ Aborted at about 600 m altitude due to a premature LIDAR setting for very-dark surface.
    - ✓ Acquired images and data from low altitude.
- Condition:
  - One-way light time between Earth and the spacecraft: about 1043 seconds (= 17 min 23 sec)

Event Timeline:

Date/Time in UTC	Event
2018-09-10T00:00 (ground)	Started preparation for descent
2018-09-11T05:27 (ground)	Gate 1 decision (Descent start = Go)
2018-09-11T06:28	Started descent, 20 km altitude, descent rate is -0.4 m/s

Date/Time in UTC	Event
2018-09-11T16:48	Changed descent rate to -0.1 m/s at about 5 km altitude
2018-09-11T17:05 (ground)	Gate 2 decision (5 km altitude check point = GO)
2018-09-12T03:57	Aborted at about 600 m altitude and ascent delta-V, ascent rate is 0.5 m/s
2018-09-12T07:30	Home position return delta-V

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time.

4.7. MINERVA-II1 deployment operation (MNRV1)

- Date: 2018-09-19 – 2018-09-21
- Description:
  - Primary purposes are as follows:
    - ✓ Deploy MINERVA-II1 Rover-1a and Rover-1b at about 55 m altitude to land on the target area (N6).
    - ✓ Test function of LIDAR NEAR mode.
  - Results
    - ✓ Deployed two rovers successfully.
    - ✓ Reached 55 m altitude.
- Condition:
  - One-way light time between Earth and the spacecraft: about 1060 seconds (= 17 min 40 sec)

Event Timeline:

Date/Time in UTC	Event
2018-09-19T00:00 (ground)	Started preparation for descent
2018-09-20T04:08 (ground)	Gate 1 decision (Descent start = Go)
2018-09-20T05:08	Started descent, 20 km altitude, descent rate is -0.4 m/s
2018-09-20T15:28	Changed descent rate to -0.1 m/s at about 5 km altitude
2018-09-20T15:46 (ground)	Gate 2 decision (5 km altitude check point = GO)
2018-09-21T01:17	Turning-on the power of the rovers
2018-09-21T03:25 (ground)	Gate 3 decision (Spacecraft autonomous & rover separation = Go)
2018-09-21T04:02	Performed vertical delta-V to slow down descent rate and horizontal delta-V of 0.2 m/s to compensate for the fast ejection velocity of the rovers
2018-09-21T04:06	Separated MINERVA-II1 Rover-1a and Rover-1b at 55 m altitude

Date/Time in UTC	Event
2018-09-21T04:07	Ascent delta-V, ascent rate is 0.4 m/s
2018-09-21T04:11	Switched antenna to XLGA-A for scanning observation maneuver
2018-09-21T04:28 (ground)	Gate 4 decision (Ascent confirmation = Confirmed)
2018-09-21T04:47	Switched antenna to XHGA (back to Earth-pointing attitude)
2018-09-21T05:05 (ground)	Gate 5 decision (Scan sequence completion = Confirmed)
2018-09-21T05:36	Home position return delta-V
2018-09-21T06:36 (ground)	Gate 6 decision (Home position return delta-V confirmation = Confirmed)

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time.

4.8. MASCOT deployment operation (MSC)

- Date: 2018-10-01 – 2018-10-04
- Description:
  - Primary purposes are as follows:
    - ✓ Deploy MASCOT at about 55 m altitude to land on the target area (MA-9).
    - ✓ Hover at about 3 km altitude and keep communication with MASCOT after the MASCOT deployment until the end of MASCOT operation.
  - Results
    - ✓ Deployed MASCOT successfully.
    - ✓ Kept communication with MASCOT until the end of MASCOT operation and received data from MASCOT.
    - ✓ Reached 51 m altitude.
- Condition:
  - One-way light time between Earth and the spacecraft: about 1085 seconds (= 18 min 05 sec)

Event Timeline:

Date/Time in UTC	Event
2018-10-01T00:00 (ground)	Started preparation for descent
2018-10-02T01:50 (ground)	Gate 1 decision (Descent start = Go)
2018-10-02T02:50	Started descent, 20 km altitude, descent rate is -0.4 m/s
2018-10-02T13:10	Changed descent rate to -0.1 m/s at about 5 km altitude
2018-10-02T13:29 (ground)	Gate 2 decision (5 km altitude check point = GO)

Date/Time in UTC	Event
2018-10-02T23:48	MASCOT final configuration
2018-10-03T00:50 (ground)	Gate 3 decision (Spacecraft autonomous & lander separation = Go)
2018-10-03T01:56	Changed descent rate to -0.03 m/s at about 60 m altitude
2018-10-03T01:57:19	Separated MASCOT at 51 m altitude
2018-10-03T01:59	Ascent delta-V, ascent rate is 0.4 m/s
2018-10-03T02:03	Switched antenna to XLGA-A for scanning observation maneuver
2018-10-03T02:21 (ground)	Gate 4 decision (MASCOT separation & ascent confirmation = Confirmed)
2018-10-03T02:40	Switched antenna to XHGA (back to Earth-pointing attitude)
2018-10-03 02:58 (ground)	Gate 5 decision (Scan sequence completion = Confirmed)
2018-10-03T05:29	Arrived at 3 km hovering altitude
2018-10-03T06:29 (ground)	Gate 6 decision (Low-altitude hovering = GO)
2018-10-03T19:30 (ground)	Mission completion announcement by MASCOT project team
2018-10-04T11:30	Home position return delta-V

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time.

Event Timeline of MASCOT on 2018-10-03:

Onboard Time (UTC)	Elapsed time	Event
01:57:23	00:00:00	Separation time
02:03:14	00:05:51	First contact with the surface at contact point CP1
02:18:51	00:15:04	Came to its 1st settlement point SP1
02:34:19	00:36:56	Performed self-uprighting and reached first measurement position MP1a. Started 1st science cycle
03:13:12	01:15:49	End of 1st day and start of 1st night on Ryugu
06:33:38 – 07:32:43		Some unintentional sliding or change of orientation have happened and moved to MP1b
07:18:28 (ground)	05:21:05	Sent command for 1st relocation
07:50:04	05:52:41	MASCOT performed its 1st relocation
07:51:38	05:54:15	End of 1st night and start of 2nd day on Ryugu

Onboard Time (UTC)	Elapsed time	Event
08:27:50	06:30:27	After the 1st relocation, reached 2nd measurement position MP2a, and started 2nd science cycle
08:30:54 – 10:42:21		Unintentional slide occurred and moved to MP2b
10:50:01	08:52:38	End of 2nd day and start of 2nd night on Ryugu
10:53:22 – 11:43:08		Unintentional slide occurred and moved to MP2c
11:16:53	09:19:30	MASMag has been turned off
15:27:11	13:29:48	End of 2nd night and start of 3rd day on Ryugu
16:30:41	14:33:18	Performed "Mini-Move" and reached 3rd measurement position MP3a and started 3rd science cycle
16:40:18 – 17:17:48		Unintentional slide occurred and moved to MP3b
18:05:41	16:08:18	After the 2nd relocation, reached 4th measurement position MP4 and started 4th science cycle
18:29:41	16:32:18	End of 3rd day and start of 3rd night on Ryugu
19:03:56 (ground)	17:06:29	End of Mission (EoM); reception of last MASCOT HK packets

Note that “ground” in the first column means time in UTC on the ground. Other value of the first column is spacecraft onboard time.

4.9. Touch-Down #1 Rehearsal 1A (TD1-R1-A)

- Date: 2018-10-13 – 2018-10-15
- Description:
  - Primary purposes are as follows:
    - ✓ Assess the feasibility of TD1 (Touch-Down #1) operation sequence.
    - ✓ Test and improve degree of skills with spacecraft operation of the operation members.
    - ✓ Assess thermal effect and characteristics of LRF at low altitude.
  - Results
    - ✓ Confirmed characteristics of LRF at low altitude and confirmed measurement values of LIDAR and LRF are continuous.
    - ✓ Achieved 10.8 m navigation accuracy with respect to Ryugu's surface.
    - ✓ Reached 22.3 m altitude.
- Condition:
  - One-way light time between Earth and the spacecraft: about 1109 seconds (= 18 min 29 sec)

Event Timeline:

Date/Time in UTC	Event
2018-10-13T22:30 (ground)	Started preparation for descent
2018-10-14T13:50 (ground)	Gate 1 decision (Descent start = Go)
2018-10-14T14:50	Started descent, 20 km altitude, descent rate is -0.4 m/s
2018-10-15T01:10	Changed descent rate to -0.1 m/s at about 5 km altitude
2018-10-15T01:28 (ground)	Gate 2 decision (5 km altitude check point = GO)
2018-10-15T12:39 (ground)	Gate 3 decision (Spacecraft autonomous & final descent = Go)
2018-10-15T13:44	Reached minimum altitude (22.3 m), ascent delta-V, ascent rate is 0.6 m/s
2018-10-15T14:12 (ground)	Gate 5 decision (Ascent confirmation = Confirmed)
2018-10-15T15:04 (ground)	Gate 6 decision (Home position return = Go)
2018-10-15T18:30	Home position return delta-V

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time.

4.10. Touch-Down #1 Rehearsal 3 (TD1-R3)

- Date: 2018-10-23 – 2018-10-25
- Description:
  - Primary purposes are as follows:
    - ✓ Assess the feasibility of TD1 operation sequence up to dropping of target marker and hovering above it.
    - ✓ Test and improve degree of skills with spacecraft operation of the operation members.
    - ✓ Assess characteristics and accuracy of LRF related to thermal effect at low altitude.
  - Results
    - ✓ Successfully released Target Marker B (TM-B) 15 m distance from the planned point.
    - ✓ Successfully tracked the released TM-B.
    - ✓ Reached 11.98 m altitude.
- Condition:
  - One-way light time between Earth and the spacecraft: about 1126 seconds (= 18 min 46 sec)

Event Timeline:

Date/Time in UTC	Event
2018-10-23T22:40 (ground)	Started preparation for descent
2018-10-24T02:39 (ground)	Gate 1 decision (Descent start = Go)

Date/Time in UTC	Event
2018-10-24T03:39	Started descent, 20 km altitude, descent rate is -0.4 m/s
2018-10-24T14:00	Changed descent rate to -0.1 m/s at about 5 km altitude
2018-10-24T14:17 (ground)	Gate 2 decision (5 km altitude check point = GO)
2018-10-25T01:28 (ground)	Gate 3 decision (Spacecraft autonomous & final descent = Go)
2018-10-25T02:37:54	Separated TM-B at 12.65 m altitude
2018-10-25T02:38:10	Reached minimum altitude (11.98 m)
2018-10-25T02:51 (ground)	Switched antenna from XHGA to XLGA-A (carrier signal only)
2018-10-25T02:52 (ground)	Gate 4 decision (Entering target marker release sequence = Confirmed)
2018-10-25T03:07 (ground)	Detected ascent delta-V on the ground
2018-10-25T03:25 (ground)	Switched antenna from XLGA-A to XHGA (telemetry back)
2018-10-25T03:26 (ground)	Gate 5 decision (Ascent confirmation = Confirmed)
2018-10-25T04:58 (ground)	Gate 6 decision (Home position return = Go)
2018-10-25T06:50	Home position return delta-V

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time.

4.11. BOX-C operation (BOX-C-2 and BOX-C-3)

- Date: 2018-10-27 – 2018-11-05
- Description:
  - Observation from 6 km altitude (BOX-C-2) and additional observation at 2.2 km altitude (BOX-C-3).
  - Acquired images of released Target Marker (TM-B).

4.12. Conjunction Orbit Operation

- Date: 2018-11-23 – 2018-12-29
- Description:
  - Sun-Earth-Probe angle was less than 3.5 degrees during this period and no communication between spacecraft and Earth was expected due to solar conjunction. Spacecraft was put into auto-return trajectory with a maximum distance to Ryugu of 108 km.

Event Timeline:

Date/Time in UTC	Event
2018-11-23	COI: Conjunction Orbit Insertion
2018-11-30	TCM1: Trajectory Correction Maneuver #1
2018-11-30	Sun-Earth-Probe (SEP) angle become less than 3 degrees
2018-12-22	Sun-Earth-Probe (SEP) angle become greater than 3 degrees
2018-12-25	TCM2: Trajectory Correction Maneuver #2
2018-12-29	HPR: Home Position Return

4.13. BOX-B operation (BOX-B-3)

- Date: 2019-01-06 – 2019-01-13
- Description:
  - Tour observation at altitude 20 km. Observation from subsolar direction.

4.14. BOX-B operation (BOX-B-4)

- Date: 2019-01-19 – 2019-01-31
- Description:
  - Tour observation at altitude 20 km: observation from north-pole direction.

4.15. Touch Down #1 (TD1-L08E1)

- Date: 2019-02-19 – 2019-02-22
- Description:
  - Primary purposes are as follows:
    - ✓ Touch down to the L08E1 area and collect samples from Ryugu.
    - ✓ Test all sequence of TD1 operation using the already-dropped target marker (TM-B).
  - Results
    - ✓ Successfully touched down and collected samples from Ryugu.
    - ✓ Achieved 1 m navigation accuracy.
    - ✓ The touch down time is 2019-02-21T22:29:10 (+- 5 sec).
- Condition:
  - One-way light time between Earth and the spacecraft: about 1141 seconds (= 19 min 01 sec)

Event Timeline:

Date/Time in UTC	Event
2019-02-19T22:00 (ground)	Started preparation for descent

Date/Time in UTC	Event
2019-02-20T23:13	Planned start time of descent (not started as planned)
2019-02-21T03:36 (ground)	Gate 1 decision (Descent start, 5 hours delay)
2019-02-21T04:13	Started descent, 20 km altitude, descent rate is -0.9 m/s
2019-02-21T08:33	Catch up to nominal orbit
2019-02-21T09:33	Changed descent rate to -0.1 m/s at about 5 km altitude
2019-02-21T10:08 (ground)	Gate 2 decision (5 km altitude check point)
2019-02-21T21:10 (ground)	Gate 3 decision (Spacecraft autonomous & final descent = GO)
2019-02-21T22:08	Changed antenna from XHGA to XLGA-A
2019-02-21T22:10	Captured target marker with GCP-NAV guidance system
2019-02-21T22:19	Target marker tracking during descent and started hovering
2019-02-21T22:27	Tilted the spacecraft and changed attitude for touch down while keeping target marker inside of the field of view and moving horizontally to over the touch down point
2019-02-21T22:29:10	Touch down, ascent delta-V, ascent rate is 0.65 m/s
2019-02-21T22:48	Touch down confirmed on the ground
2019-02-21T22:50	Changed antenna from XLGA-A to XHGA
2019-02-21T23:09 (ground)	Gate 5 check (Ascent confirmation & success confirmation)
2019-02-22T01:30 (ground)	Gate 6 decision (Home position return)
2019-02-22T01:40	Sample settling maneuver
2019-02-22T02:20	Closed sampler container room A
2019-02-22T04:00	Changed spacecraft attitude to Sun-pointing
2019-02-22T04:30	Performed return delta-V
2019-02-22T04:40	Changed spacecraft attitude to Earth-pointing
2019-02-23T03:00	Returned to the home position

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time.

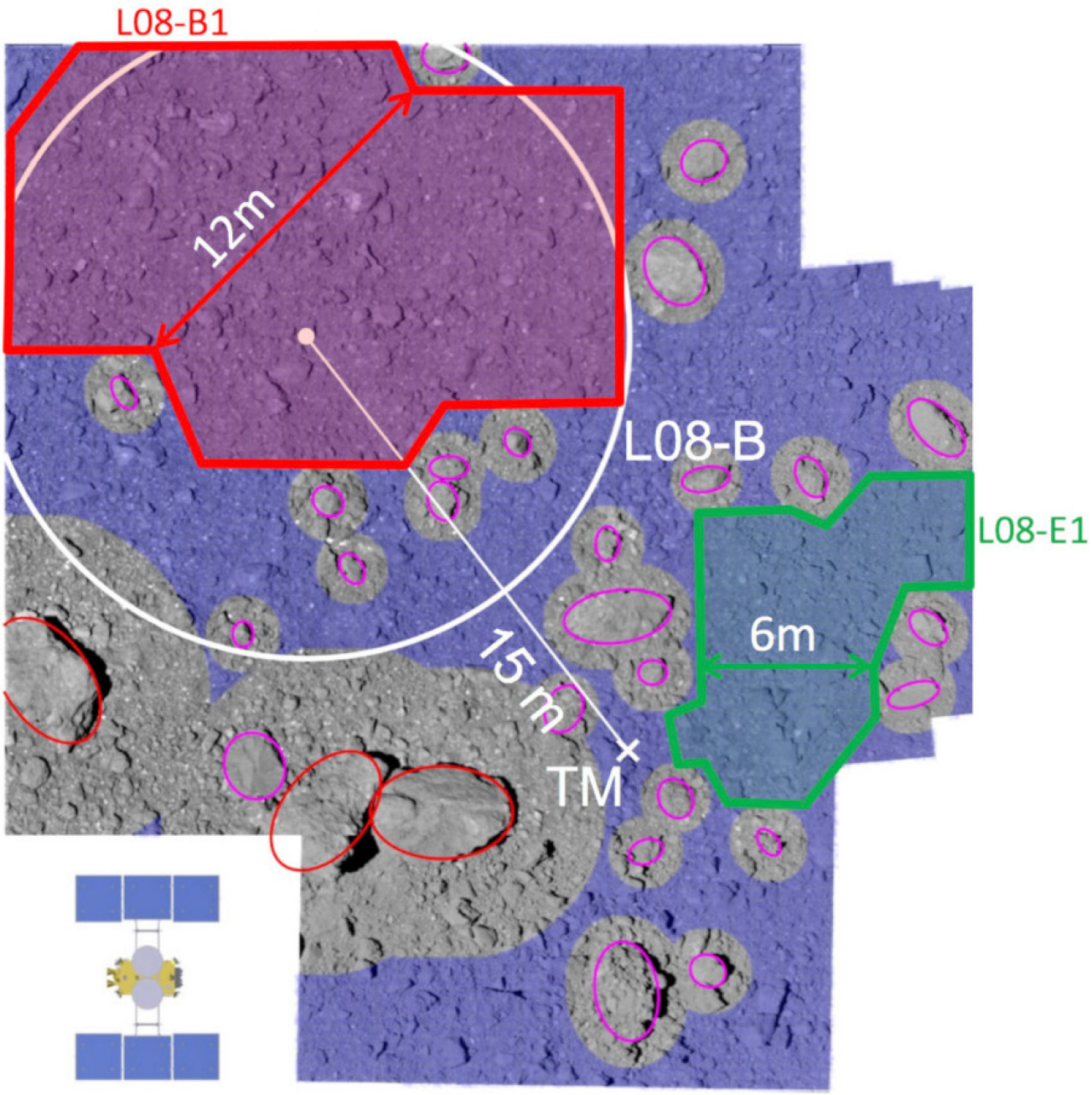

Figure 3 Touchdown candidate sites L08-B1 (red) and L08-E1 (green). The white circle indicates the area of L08-B, while the cross is the location of the landed target marker. Credit: JAXA

4.16. BOX-C operation (BOX-C-4)

- Date: 2019-02-23 – 2019-03-01
- Description:
  - Descent observation. Lowest altitude is about 5 km.

4.17. Low Altitude Descent Observation (DO-S01)

- Date: 2019-03-05 – 2019-03-08
- Description:
  - Primary purposes are as follows:
    - ✓ Acquire images for safety evaluation at S01 area by Descent Observation.
  - Results
    - ✓ Successfully observed S01 area.
    - ✓ Reached 22 m altitude.
- Condition:
  - One-way light time between Earth and the spacecraft: about 1115 seconds (= 18 min 35 sec)

Event Timeline:

Date/Time in UTC	Event
2019-03-05T22:40 (ground)	Started preparation for descent
2019-03-07T03:40 (ground)	Gate 1 decision (Descent start = GO)
2019-03-07T04:27	Started descent, 20 km altitude, descent rate is -0.4 m/s
2019-03-07T14:47	Changed descent rate to -0.1 m/s at about 5 km altitude
2019-03-07T15:06 (ground)	Gate 2 decision (5 km altitude check point)
2019-03-08T02:46 (ground)	Gate 3 decision (Spacecraft autonomous & final descent)
2019-03-08T03:24:13	Reached minimum altitude (22 m)
2019-03-08T04:47 (ground)	Gate 5 check (Ascent confirmation)
2019-03-08T07:40 (ground)	Gate 6 decision (Home position return)

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time.

4.18. Crater search descent pre-impact operation (CRA1)

- Date: 2019-03-19 – 2019-03-21
- Description:
  - Primary purposes are as follows:
    - ✓ Investigate planned impact area before SCI operation.
  - Results
    - ✓ Observed planned impact area successfully.
- Condition:
  - One-way light time between Earth and the spacecraft: about 1085 seconds (= 18 min 05 sec)

Event Timeline:

Date/Time in UTC	Event
2019-03-19T22:41 (ground)	Started preparation for descent
2019-03-20T22:57 (ground)	Gate 1 decision (Descent start = GO)
2019-03-20T23:57	Started descent, 20 km altitude, descent rate is -0.4 m/s
2019-03-21T10:17	Changed descent rate to -0.1 m/s at about 5 km altitude
2019-03-21T10:35 (ground)	Gate 2 decision (5 km altitude check point = GO)
2019-03-21T17:15 (ground)	Gate 3 decision (Crater search = GO)
2019-03-21T18:51	Switched antenna from XHGA to XLGA-A (telemetry blackout)
2019-03-21T19:55	Switched antenna from XLGA-A to XHGA (telemetry back)
2019-03-21T20:11 (ground)	Gate 5 check (Ascent confirmation = Confirmed)

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time.

4.19. Small Carry-on Impactor operation (SCI)

- Date: 2019-04-02 to 2019-04-05
- Description:
  - Primary purposes are as follows:
    - ✓ Release SCI at planned position and perform impact experiment.
    - ✓ Release DCAM3 at planned position.
    - ✓ Evacuate to safe backside of Ryugu from the impact point when impact occurred.
    - ✓ Return to the home position through safety path after the impact.
  - Results
    - ✓ Successfully done.
- Condition:
  - One-way light time between Earth and the spacecraft: about 1050 seconds (= 17 min 30 sec)

Event Timeline:

Date/Time in UTC	Event
2019-04-02T23:00 (ground)	Started preparation for descent
2019-04-04T03:12 (ground)	Gate 1 decision (Descent start = GO)
2019-04-04T04:00	Started descent, 20 km altitude, descent rate is -0.4 m/s
2019-04-04T14:20	Changed descent rate to -0.1 m/s at about 5 km altitude

Date/Time in UTC	Event
2019-04-04T14:55 (ground)	Gate 2 decision (5 km altitude check point = GO)
2019-04-05T00:57 (ground)	Gate 3 decision (SCI separation = GO)
2019-04-05T01:44	Reached 500 m altitude and started hovering
2019-04-05T01:56	Released SCI at about 500 m altitude
2019-04-05T01:57	Started ejecta and debris escape sequence, escape delta-V #1
2019-04-05T02:02	Escape delta-V #2
2019-04-05T02:11	Escape delta-V #3
2019-04-05T02:14	Released DCAM3
2019-04-05T02:15	Escape delta-V #4
2019-04-05T02:36	SCI Ignition
2019-04-05T02:41	Escape delta-V #5
2019-04-05T02:46	Escape delta-V #6, slowed down speed
2019-04-05T02:50 (ground)	Confirmed communication with DCAM3
2019-04-05T02:56 (ground)	Post-SCI Ignition Spacecraft Health Check = OK
2019-04-05T04:14	Escape-descent-stop delta-V
2019-04-05T04:45 (ground)	Gate 5 check (Escape-descent stop confirmation = Confirmed)
2019-04-05T06:12 (ground)	Gate 6 check (Transition to the home position return operation = GO)
2019-04-05T06:44	Home position return delta-V #1
2019-04-05T08:14	Home position return delta-V #2

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time.

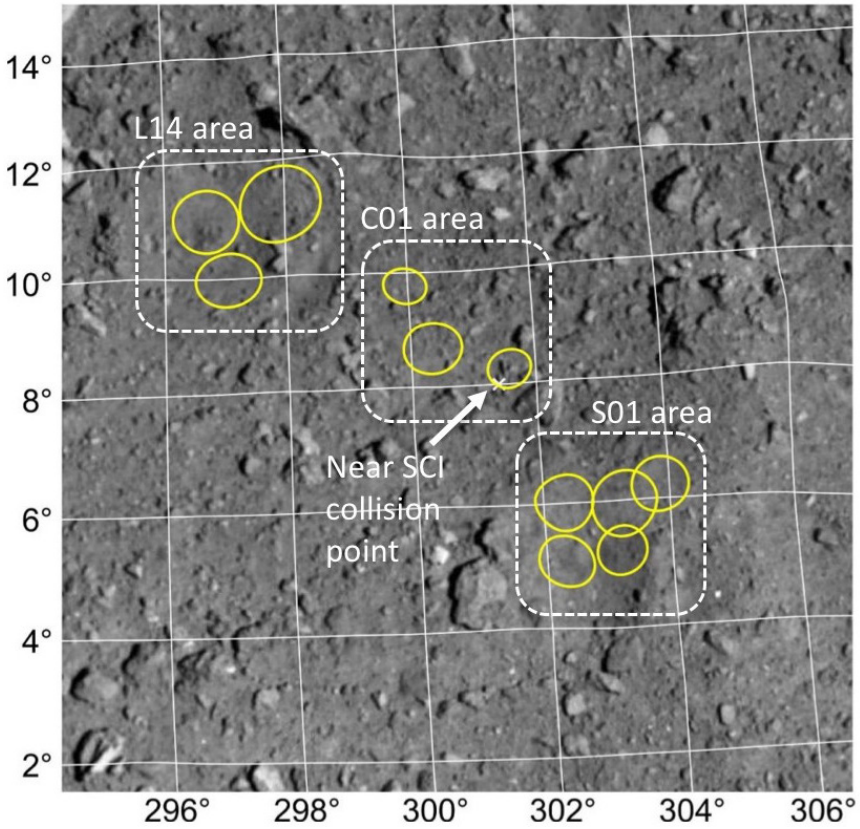

Figure 4 Region near the SCI collision point before the SCI operation. Credit: JAXA, Univ. of Tokyo, Kochi Univ., Rikkyo Univ., Nagoya Univ., Chiba Institute of Technology, Meiji Univ., Univ. of Aizu, AIST.

4.20. Crater search descent post-impact operation (CRA2)

- Date: 2019-04-22 to 2019-04-25
- Description:
  - Primary purposes are as follows:
    - ✓ Search crater around SCI impact area after impact operation and observe it.
  - Results
    - ✓ Acquired images on SCI impact area successfully.
- Condition:
  - One-way light time between Earth and the spacecraft: about 997 seconds (= 16 min 37 sec)

Event Timeline:

Date/Time in UTC	Event
2019-04-22T23:26 (ground)	Started preparation for descent
2019-04-24T06:42 (ground)	Gate 1 decision (Descent start = GO)
2019-04-24T07:42	Started descent, 20 km altitude, descent rate is -0.4 m/s

Date/Time in UTC	Event
2019-04-24T18:02	Changed descent rate to -0.1 m/s at about 5 km altitude
2019-04-24T18:38 (ground)	Gate 2 decision (5 km altitude check point = GO)
2019-04-25T01:11 (ground)	Gate 3 decision (Crater search = GO)
2019-04-25T02:16	Reached minimum altitude, about 1.7 km, started hovering
2019-04-25T02:35	Switched antenna from XHGA to XLGA (telemetry blackout)
2019-04-25T02:38	Started observation of SCI impact area
2019-04-25T03:12 (ground)	Gate 4 check (Hovering confirmation = Confirmed)
2019-04-25T03:31	Stopped observation of SCI impact area
2019-04-25T03:38	Switched antenna from XLGA to XHGA (telemetry back)
2019-04-25T03:53	Ascent delta-V
2019-04-25T03:54 (ground)	Gate 5 check (Ascent confirmation = Confirmed)
2019-04-25T06:45	Home position return delta-V

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time.

4.21. Pin-point Touchdown Rehearsal 1 (PPTD-TM1)

- Date: 2019-05-13 – 2019-05-17
- Description:
  - Primary purposes are as follows:
    - ✓ Drop target marker to the target area, S01.
    - ✓ Acquire information on elevation of terrain of S01 region.
    - ✓ Assess the feasibility of target marker dropping sequence without using LRF for navigation and control.
  - Results
    - ✓ Aborted at the 50 m altitude due to misconfiguration of changing LIDAR signal reception gain.
    - ✓ Successfully acquired images of S01 region and another candidate region, C01.
- Condition:
  - One-way light time between Earth and the spacecraft: about 940 seconds (= 15 min 40 sec)

Event Timeline:

Date/Time in UTC	Event
2019-05-13T21:10 (ground)	Started preparation for descent
2019-05-15T02:47 (ground)	Gate 1 decision (Descent start = GO)
2019-05-15T03:31	Started descent, 20 km altitude, descent rate is -0.4 m/s
2019-05-15T13:51	Changed descent rate to -0.1 m/s at about 5 km altitude
2019-05-15T14:15 (ground)	Gate 2 decision (5 km altitude check point = GO)
2019-05-16T01:34 (ground)	Gate 3 decision (Spacecraft autonomous & final descent = GO)
2019-05-16T02:25	Aborted autonomously at about 50 m altitude, ascent delta-V, ascent rate is 0.8 m/s
2019-05-16T02:3x	Acquired images of C01 and S01 regions during ascent
2019-05-16T08:30	Home position return delta-V
2019-05-17T02:00	Returned to the home position

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time. Note that blue-colored rows are the events related to scientific observation.

4.22. Pin-point Touchdown Rehearsal 1A (PPTD-TM1A)

- Date: 2019-05-27 – 2019-05-30
- Description:
  - Primary purposes are as follows:
    - ✓ Drop target marker to the target area, C01-C.
    - ✓ Acquire information on elevation of terrain of C01 region.
    - ✓ Assess the feasibility of target marker dropping sequence without using LRF for navigation and control.
  - Results
    - ✓ Successfully dropped target marker A (TM-A) to the target area, C01-C, with 3 m distance to the planned point.
- Condition:
  - One-way light time between Earth and the spacecraft: about 903 seconds (= 15 min 03 sec)

Event Timeline:

Date/Time in UTC	Event
2019-05-27T23:00 (ground)	Started preparation for descent

Date/Time in UTC	Event
2019-05-29T02:18 (ground)	Gate 1 decision (Descent start = GO)
2019-05-29T03:06	Started descent, 20 km altitude, descent rate is -0.4 m/s
2019-05-29T13:26	Changed descent rate to -0.1 m/s at about 5 km altitude
2019-05-29T13:50 (ground)	Gate 2 decision (5 km altitude check point = GO)
2019-05-30T01:14 (ground)	Gate 3 decision (Spacecraft autonomous & final descent = GO)
2019-05-30T01:44 (ground)	Gate 4 check (Pre-Target Marker release delta-V = Confirmed)
2019-05-30T02:00	Reached 35 m altitude; started hovering and measuring altitude by LRF, while altitude was controlled by LIDAR
2019-05-30T02:09	After horizontal delta-V to synchronize with Ryugu's rotation, started falling to drop TM-A
2019-05-30T02:18:42	Released TM-A, ascent delta-V at about 8 m altitude
2019-05-30T02:24:53	"Observation for DEM" maneuver #1
2019-05-30T02:33:13	"Observation for DEM" maneuver #2
2019-05-30T02:54:53	"Observation for DEM" maneuver #3
2019-05-30T03:20 (ground)	Gate 5 check (Ascent confirmation = Confirmed)
2019-05-30T06:00 (ground)	Gate 6 decision (Home position return = GO)
2019-05-30T07:00	Home position return delta-V

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time.

4.23. Pin-point Touchdown Rehearsal 1B (PPTD-TM1B)

- Date: 2019-06-10 – 2019-06-13
- Description:
  - Primary purposes are as follows:
    - ✓ Check function and acquire data of LRF and Target Marker Tracking (TMT).
    - ✓ Acquire data on terrain information on C01 region.
  - Results
    - ✓ Successfully observed C01 region and crater created by SCI.
    - ✓ Acquired data on spacecraft behavior at low altitude.
    - ✓ Reached about 9 m altitude.
- Condition:
  - One-way light time between Earth and the spacecraft: about 869 seconds (= 14 min 29 sec)

Event Timeline:

Date/Time in UTC	Event
2019-06-10T23:00 (ground)	Started preparation for descent
2019-06-12T01:54 (ground)	Gate 1 decision (Descent start = GO)
2019-06-12T02:40	Started descent, 20 km altitude, descent rate is -0.4 m/s
2019-06-12T13:00	Changed descent rate to -0.1 m/s at about 5 km altitude
2019-06-12T13:17 (ground)	Gate 2 decision (5 km altitude check point = GO)
2019-06-13T00:43 (ground)	Gate 3 decision (Spacecraft autonomous & final descent = GO)
2019-06-13T01:34	Reached about 35 m altitude; started hovering and measuring altitude by LRF, while altitude was controlled by LIDAR
2019-06-13T01:43	After horizontal delta-V to synchronize with Ryugu's rotation, started falling
2019-06-13T01:53	Reached about 9 m altitude and performed ascent delta-V
2019-06-13T01:58:26	"Observation for DEM" maneuver #1
2019-06-13T02:03:36	"Observation for DEM" maneuver #2
2019-06-13T02:25:16	"Observation for DEM" maneuver #3
2019-06-13T02:54 (ground)	Gate 5 check (Ascent confirmation = Confirmed)
2019-06-13T05:04 (ground)	Gate 6 decision (Home position return = GO)
2019-06-13T05:30	Home position return delta-V

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time.

4.24. Pin-point Touchdown operation (PPTD)

- Date: 2019-07-08 – 2019-07-12
- Description:
  - Primary purposes are as follows:
    - ✓ Touch down to C01-Cb region using Target Marker A (TM-A) and acquire sample of Ryugu.
  - Results
    - ✓ Successfully touch down to the target area, C01-Cb.
    - ✓ Achieved 60 cm navigation accuracy.
- Condition:
  - One-way light time between Earth and the spacecraft: about 816 seconds (= 13 min 36 sec)

Event Timeline:

Date/Time in UTC	Event
2019-07-08T21:30 (ground)	Started preparation for descent
2019-07-10T00:58 (ground)	Gate 1 decision (Descent start = GO)
2019-07-10T01:46	Started descent, 20 km altitude, descent rate is -0.4 m/s
2019-07-10T12:06	Changed descent rate to -0.1 m/s at about 5 km altitude
2019-07-10T12:36 (ground)	Gate 2 decision (5 km altitude check point = GO)
2019-07-11T00:04 (ground)	Gate 3 decision (Spacecraft autonomous & final descent = GO)
2019-07-11T00:40:20	Started hovering at 30 m altitude
2019-07-11T00:47	Switched antenna from XHGA to XLGA-A, telemetry blackout (carrier signal only)
2019-07-11T00:47:22	Started tracking of TM-A
2019-07-11T00:48:08	Started diving to 8.5 m altitude autonomously
2019-07-11T00:53:13	Started six degrees of freedom control using measurement values by LRF at 17 m altitude
2019-07-11T00:54:13	Waited convergence of position and velocity of the spacecraft at 12.5 m altitude
2019-07-11T00:56:26	Waited convergence of position and velocity of the spacecraft at 8.5 m altitude
2019-07-11T00:58:23	Tilted spacecraft and changed attitude for touch down while keeping target marker inside of the field of view and moving horizontally to over the touch down point at 8.5 m altitude
2019-07-11T00:59:30	Started hovering keeping distance to TM-A
2019-07-11T01:01 (ground)	Gate 4 check (Switched to XLGA-A = Confirmed)
2019-07-11T01:03:53	Stopped hovering keeping distance to TM-A
2019-07-11T01:04:55	Started final descent
2019-07-11T01:05:10	Started attitude control by reaction wheels to prevent vibration of the sampler horn
2019-07-11T01:06:18	Detected Touch down by LRF-S2, ejected projectile, triggered ascent delta-V, ascent rate is 0.65 m/s
2019-07-11T01:06:29	Stopped attitude control by reaction wheels and started attitude control by RCS

Date/Time in UTC	Event
2019-07-11T01:25	Switched antenna from XLGA-A to XHGA, telemetry back
2019-07-11T02:10 (ground)	Gate 5 check (Touch down success confirmation = Success)
2019-07-11T04:40	Sample scoop-up maneuver; slow down delta-V, decelerated ascent velocity only 0.02 m/s
2019-07-11T05:10	Closed sample container room C
2019-07-11T05:46 (ground)	Gate 6 decision (Home position return = GO)
2019-07-11T07:00	Home position return delta-V #1
2019-07-11T08:10	Home position return delta-V #2
2019-07-12T01:37	Returned to the home position

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time.

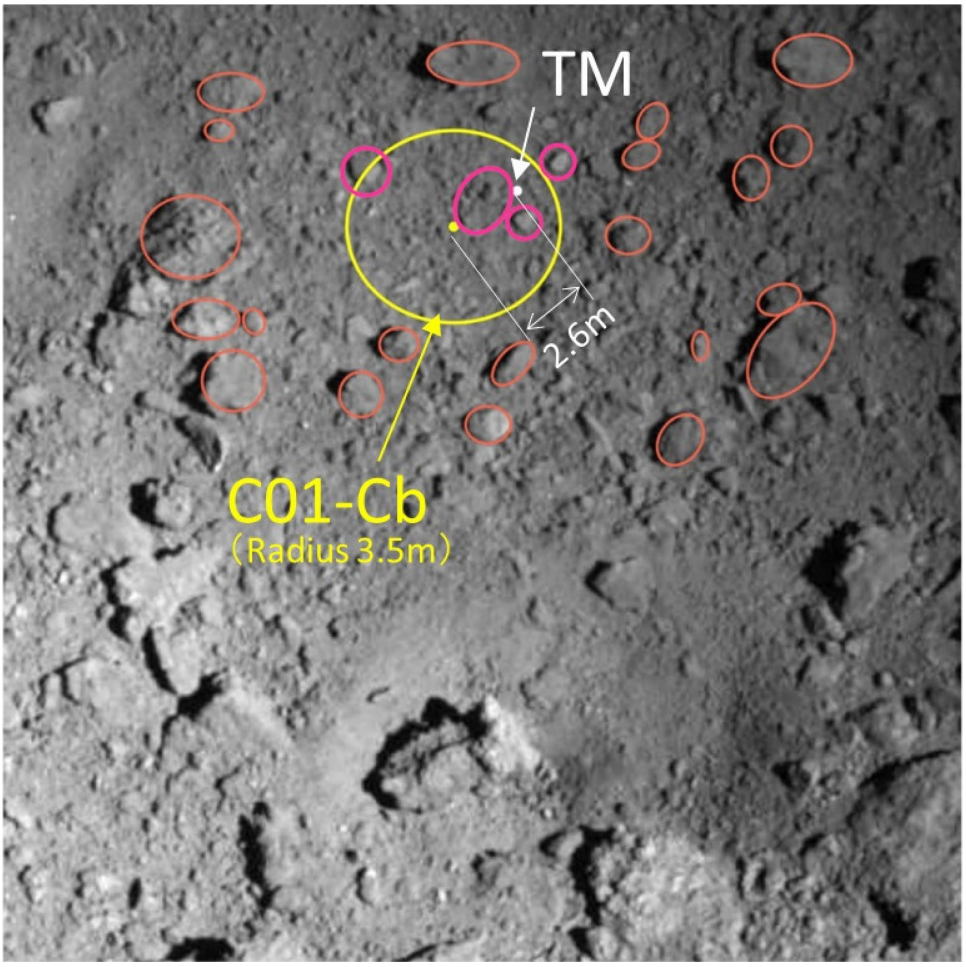

Figure 5 Region near the C01-Cb area. Credit: JAXA, Univ. of Tokyo, Kochi Univ., Rikkyo Univ., Nagoya Univ., Chiba Institute of Technology, Meiji Univ., Univ. of Aizu, AIST.

4.25. BOX-C operation (BOX-C-5)

- Date: 2019-07-20 – 2019-07-31
- Description:
  - Observation of PPTD area from 5 km altitude.

4.26. BOX-B operation (BOX-B-5)

- Date: 2019-08-08 – 2019-08-14
- Description:
  - Tour observation at 20 km altitude; observation of evening direction.

4.27. BOX-B operation (BOX-B-6)

- Date: 2019-08-14 – 2019-08-27
- Description:
  - Tour observation at 20 km altitude; observation of morning direction.

4.28. Target Markers Orbiting operation (TM-ORB)

- Date: 2019-09-11 – 2019-09-22
- Description:
  - Primary purposes are as follows:
    - ✓ Use two Target Markers for precise gravity field measurement.
    - ✓ Insert two Target Markers (TM-E and TM-C) to equatorial orbit and polar orbit from 1.5 km altitude.
    - ✓ Observe two Target Markers from 20 km away from Ryugu above sub-solar point.
  - Results
    - ✓ Two target markers TM-E and TM-C are successfully released and orbited several days around Ryugu.
    - ✓ Note that TM-E was named "Explorer", and TM-C was named "Sputnik".
- Condition:
  - One-way light time between Earth and the spacecraft: about 788 seconds (= 13 min 08 sec)

Event Timeline:

Date/Time in UTC	Event
2019-09-11T23:00 (ground)	Started preparation for descent

Date/Time in UTC	Event
2019-09-12T01:30	TCM1 (Trajectory Correction Maneuver #1), started descent at 20 km altitude, descent rate is -3 mm/s
2019-09-13T00:00	TCM2 at 19 km altitude
2019-09-14T00:00	TCM3 at 17 km altitude
2019-09-15T00:00	TCM4 at 13 km altitude
2019-09-16T00:00	TCM5 at 6 km altitude
2019-09-16T10:30 (ground)	Go/No Go decision (Target Makers separation = GO)
2019-09-16T16:14:20	delta-V #1 (Establishing TM-E orbit insertion velocity)
2019-09-16T16:17:40	Separated TM-E and inserted it to equatorial orbit
2019-09-16T16:17:50	delta-V #2 (Clearing out TM-E separation envelope)
2019-09-16T16:21:20	delta-V #3 (Establishing TM-C orbit insertion velocity)
2019-09-16T16:24:20	Separated TM-C and inserted it to polar orbit
2019-09-16T16:24:30	delta-V #4 (Clearing out TM-C separation envelope)
2019-09-16T16:27:40	delta-V #5 (Ascent to the TM-observation point)
2019-09-17T02:10	TCM6 (Heading to hovering observation point)
2019-09-17T11:15	TCM7 (Arrival at hovering observation point)
2019-09-17T12:00	Started observation of TM-E and TM-C by ONC-T and ONC-W1 above sub-solar point
2019-09-22T16:00	Stopped observation of TM-E and TM-C

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time. Note that blue-colored rows are the events related to scientific observation.

4.29. BOX-B operation (BOX-B-7)

- Date: 2019-09-23 – 2019-09-27
- Description:
  - Tour observation at 20 km altitude: Observation of evening direction and from nearby position of sub-solar point.

4.30. MINERVA-II2 Orbiting operation (MNRV-ORB)

- Date: 2019-09-27 – 2019-10-02
- Description:

- Primary purposes are as follows:
  - ✓ Use MINERVA-II2 Rover-2 for precise gravity field measurement by inserting MINERVA-II2 Rover-2 to orbit from 1.5 km altitude and observing MINERVA-II2 Rover-2 continuously.
- Results
  - ✓ MINERVA-II2 Rover-2 is successfully released and orbited about 22 hours around Ryugu.

- Condition:
  - One-way light time between Earth and the spacecraft: about 800 seconds (= 13 min 20 sec)

Event Timeline:

Date/Time in UTC	Event
2019-09-27T23:00 (ground)	Started preparation for descent
2019-09-28T01:30	TCM1, started descent at 20 km altitude, descent rate is -26 mm/s
2019-09-29T01:30	TCM2 at 17 km altitude
2019-09-30T00:00	TCM3 at 14 km altitude
2019-10-01T00:00	TCM4 at 11 km altitude
2019-10-02T00:00	TCM5 at 6 km altitude
2019-10-02T10:30 (ground)	Go/No Go decision (MINERVA-II2 separation = GO)
2019-10-02T15:54:00	delta-V #1 (Establishing MINERVA-II2 orbit insertion velocity)
2019-10-02T15:57:20	Separated MINERVA-II2 at 1 km altitude
2019-10-02T16:00:40	delta-V #2 (Ascent to the MINERVA-II2 observation point)
2019-10-02T23:00	delta-V #3 (Arrival to the MINERVA-II2 observation point, 8 km altitude)

Note that “ground” in the first column means date/time in UTC on the ground. Other value of the first column is spacecraft onboard time. Note that blue-colored rows are the events related to scientific observation.

4.31. BOX-C operation (BOX-C-6)

- Date: 2019-10-08 – 2019-10-14
- Description:
  - Altitude 8 km, BOX-C observation keeping the orbit of the spacecraft for observation of MINERVA-II2.

4.32. BOX-C operation (BOX-C-7)

- Date: 2019-10-19 – 2019-10-30
- Description:

- PPTD area observation from about 4 km altitude

5. References

Ho et al., The MASCOT lander aboard Hayabusa2: The in-situ exploration of NEA (162173) Ryugu, *Planetary and Space Science*, **200**, 105200, https://doi.org/10.1016/j.pss.2021.105200, 2021.

Jaumann et al., Images from the surface of asteroid Ryugu show rocks similar to carbonaceous chondrite meteorites, *Science*, **365**, 817 – 820, https://doi.org/10.1126/science.aaw8627, 2019.

Scholten et al., The descent and bouncing path of the Hayabusa2 lander MASCOT at asteroid (162173) Ryugu, *Astronomy & Astrophysics*, **632**, L3, https://doi.org/10.1051/0004-6361/201936757, 2019.

Scholten et al., The Hayabusa2 lander MASCOT on the surface of asteroid (162173) Ryugu – Stereo-photogrammetric analysis of MASCam image data, *Astronomy & Astrophysics*, **632**, L5, https://doi.org/10.1051/0004-6361/201936760, 2019.

Suzuki et al., Initial inflight calibration for Hayabusa2 optical navigation camera (ONC) for science observations of asteroid Ryugu, *Icarus*, **300**, 341 – 359, https://doi.org/10.1016/j.icarus.2017.09.011, 2018.

Takei et al., Hayabusa2's station-keeping operation in the proximity of the asteroid Ryugu, *Astrodynamics*, **4**, 349 – 375, https://doi.org/10.1007/s42064-020-0083-8, 2020.