

## Planetary Exploration in a Coming Decade Activity: Suggestions from the 2nd-stage committee to proposals

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Japanese Planetary Science Society started "Planetary Exploration in a Coming Decade" activity in 2010 aiming to organize a new mission to be launched between 2017 and 2027. The second stage of the activity accepted 13 proposals last December. Among them, 8 groups aim new missions, and 5 groups proposes new instruments. The 2nd-stage committee members reviewed each proposal to return comments to improve the proposals from scientific views. We briefly report outline of the discussions held among the committee members.

Keywords: planetary exploration

## Conceptual Study on SLIM - Lunar Landing Demonstration via Small Explorer

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Authors keep perusing the possibility of lunar exploration via small spacecraft. It will enlarge the opportunities of exploration. Especially, high risk challenging missions would become realistic with the small spacecraft. As a first step, smart pin-point landing technology demonstrator, named as SLIM (Smart Lander for Investigating Moon) is now under conceptual study. This paper summarizes the status of SLIM study.

Keywords: Lunar exploration, Soft Landing

## Lunar landing missions for in-situ dating of impact-melt rocks

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In this talk, we suggest a series of lunar landing missions for in-situ dating of impact-melt rocks.

Keywords: moon, radioactive dating, lunar exploration, cratering chronology

## Proposed sample return mission from the lunar farside highland

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Compositional information of the lunar highland is important for understanding the bulk composition and solidification of the lunar magma ocean and for estimating the internal structure of the Moon. However, recent studies [1][2] indicate that the previous understanding [3] of the lunar highland composition based primarily on the lunar samples returned from the nearside by Apollo and Luna missions is insufficient for understanding the overall crustal composition because more primitive highland materials with different composition from the current sample collection, which we do not have, are present in the farside highland.

Therefore, we are proposing a sample return mission to the lunar farside highland to fill the gap in our knowledge by obtaining the most primitive highland material and investigating such previously unknown samples. Information from these samples, such as crystallization age, major and trace element composition, isotopic composition, and crystal texture, are important for understanding the cooling and solidification history of the lunar magma ocean, formation of the crust, degree of differentiation when the highland material crystallized, and composition of the bulk lunar magma ocean.

A region around Freundlich-Sharonov and Dirichlet-Jackson basin where Th content is the lowest [1] and the Mg# (Mg/[Mg+Fe] in mole percent in mafic minerals) is the highest [2], both suggesting that this region is the most primitive highland on the lunar surface, is a potential sampling site. The proposed mission consists of one lander with return capability, a manipulator to collect both regolith and small (a few centimeters in diameter) rocks from around the lander, and spectral cameras for sample selection. Further study is required to estimate the minimum sample requirement of sample number and weight to achieve our scientific goal.

[1] S. Kobayashi, LPSC, #1795 (2010).

[2] M. Ohtake et al., LPSC, #1977 (2011).

[3] P. Warren, Am. Mineralogist, 78, 360-376 (1993).

Keywords: sample return, Moon, farside highland, primitive highland material

## Mars atmospheric escape exploration

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The Mars atmospheric escape exploration working group (post-Nozomi mission WG), established on December 2011, has been investigating a mission to study the atmospheric escape from Mars with emphases placed on its possible impacts on the climate change on early Mars and on understanding the habitable zone of unmagnetized terrestrial planets. Although this mission is not proposed to the category of "next decade initiatives for lunar planetary explorations", we consider it fruitful to discuss possible collaborations with relevant research communities. SGEPS's activities toward planetary exploration will be also presented.

Keywords: Mars, Atmospheric escape, Plasma, Exploration

## Possibility of Lightning and thundercloud observation in Jupiter by JUICE and ground-based-telescope

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Lightning measurement is an excellent way to explore the planetary atmosphere like as in the Earth based on the knowledge of the relationship between the atmospheric dynamics and electrical charge. It has been suggested for a decade that thunderstorms in Jupiter take important roles not only in the investigation of meteorology, which determines the large scale structures such as belt/zone and big ovals, but also in probing the water abundance of the deep atmosphere, which is crucial to constrain the behavior of volatiles in early solar system. Here we suggest lightning measurement with optical camera onboard spacecraft especially in JUICE mission and on a

ground-based telescope. Making use of two H Balmer Alpha line at 656.3 nm filters, the information on the depth of lightning discharge could be derived.

We are suggesting such functions to the onboard camera of JUICE and also plan to try to detect lightning flashes with a 1.6 m reflector of Hokkaido University.

Keywords: Jupiter, thunderstorm, lightning, JUICE, telescope

## Enceladus' exploration: chemical and biological investigations of water-rich plumes

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One of the most remarkable findings by the Cassini mission is perhaps water-rich plumes erupting from warm fractures near the south-pole region of Enceladus. Given such geological activities and detection of sodium-rich salts in the plumes, Enceladus is highly likely to have an interior liquid ocean interacting with rock materials. These observations raise some primary questions regarding planetary sciences and astrobiology: What is the chemical composition of Enceladus ocean? What kinds of metabolic energy source are available? How and when was Enceladus ocean formed? Does the chemical evolution proceed in the ocean? And, is there life there? Answering these questions would provide a dramatic advance in our understanding of habitability of life in the solar system and could be big breakthrough in almost all fields of natural sciences, including earth sciences, biology, chemistry, and astronomy.

Here we propose a chemical and biological exploration for Enceladus plumes with in-situ and sample-return analyses. In-situ mass spectroscopy with a high-resolution multi-turn TOF MS ( $m/z = 2?1000$ ) would provide the abundances and isotopic compositions of major components of the ocean. Such observational data would allow us to discuss 1) the origin and distribution of volatiles in the Saturn-forming region of the early solar system, 2) biological signatures recorded as anomalies in abundance and/or isotopic compositions, and 3) possible metabolic reactions and energy for chemithoautotrophy. Microscopic analyses for returned samples include synchrotron X-ray analyses, chemical and mineralogical analyses with a nano-SIMS, and calorimetry with radioactive isotopic tracers. Based on results from these analyses, we will be able to 4) characterize physical and chemical conditions of the ocean (pH, hydrogen fugacity, and temperature), 5) discuss the chemical evolution of organic compounds (chemical structure and interactions with minerals), and 6) detect a signature of biological activities.

Keywords: planetary exploration, Saturn, icy satellite, Enceladus, ocean

## Sample return from 107P/Wilson-Harrington

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We propose Sample Return mission from 107P/Wilson-Harrington, which is a dormant comet that potentially preserve pristine minerals, ice, and organics in the early solar system. Several sample return missions from primitive undifferentiated asteroids, such as Hayabusa-2, Osiris-REx, and MarcoPolo-R, have been planned to obtain samples from near-Earth C-type or related asteroids. Compared to those asteroids, 107P/Wilson-Harrington may preserve ice in its interior, and sample return of pristine ice is expected in the proposed mission.

Keywords: sample return, primitive bodies, Wilson-Harrington



## Deep Space Exploration Technology Experiment Mission DESTINY

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DESTINY which stands for 'Demonstration and Experiment of Space Technology for INterplanetary voYage' is a mission candidate for the 3rd mission of ISAS small science satellite series. The 3rd mission is planned to be decided in 2012, and the select one is scheduled to be launched in 2017.

As illustrated in the Figure, DESTINY will be launched by an Epsilon launch vehicle and firstly placed into a low elliptical orbit, where then its altitude raised by the use of ion engine. When the orbit raising reaches the Moon, DESTINY subsequently is injected into transfer orbit for L<sub>2</sub> Halo orbit of the Sun-Earth system by using lunar gravity assist. Upon arrived at L<sub>2</sub> Halo orbit, DESTINY will conduct its engineering experiment as well as scientific observations for at least a half year. If conditions permit, DESTINY will leave L<sub>2</sub> Halo orbit, and transfer to the next destination.

On the way to L<sub>2</sub> Halo orbit, DESTINY will conduct demonstration and experiment on key advanced technologies for future deep space missions. Major items of the technology demonstration are listed as follows.

### **1. High energy mission by Epsilon rocket**

We investigate appropriate rocket configurations and flight path designs, and evaluate the performance of Epsilon rocket to insert spacecrafts into high energy orbits. It provides basic data of Epsilon rocket application to deep space missions.

### **2. Ultra-Lightweight solar panel**

In order to generate large electric power to run m20 ion engine, 'Ultra-Lightweight Solar Panel', which is under development at JAXA, is applied and its performance is evaluated. This solar panel is estimated to achieve power to mass ratio at least double to conventional ones. Future application is expected in outer planet probes (JMO, MELOS) or probes with large ion engines.

### **3. Large scale ion engine m20**

DESTINY is inserted into an elliptical orbit and reaches to a Halo orbit by its own orbital maneuver. For this maneuver, a large ion engine (m20) which is under R&D at JAXA will be adopted and its performance is evaluated. This ion engine has thrust five times as much as m10 used by Hayabusa and will be expected to be applied to large probes such as SOLAR-D or Hayabusa Mk2.

### **4. Advanced thermal control**

In order to manage large amount of heat generated by the large ion engine, advanced thermal control techniques by way of Loop Heat Pipe will be adopted.

### **5. Orbit determination under low thrust operation**

DESTINY will reach to Halo orbit by running ion engine over long duration. In order to reduce burdens to shut down the ion engine each time of orbit determinations, orbit determination under ion engine operation is conducted and its performance is evaluated.

### **6. Automatic/autonomous onboard operation**

In order to increase the efficiency of operation, autonomous and highly functioned spacecraft management system is developed demonstrated on board. This technique is expected to be adopted especially in the deep space missions usually operated under severe communication condition.

### **7. Halo orbit transfer and maintenance**

DESTINY will reach to Halo orbit and maintains the orbit more than one period. In order to reduce the risks of Halo orbit insertion and suppress the amount of orbital maneuvers, the orbit control technique using dynamical system theory is used and its operability is evaluated. This technique will be adopted in SPICA, which will be operated in Halo orbit.

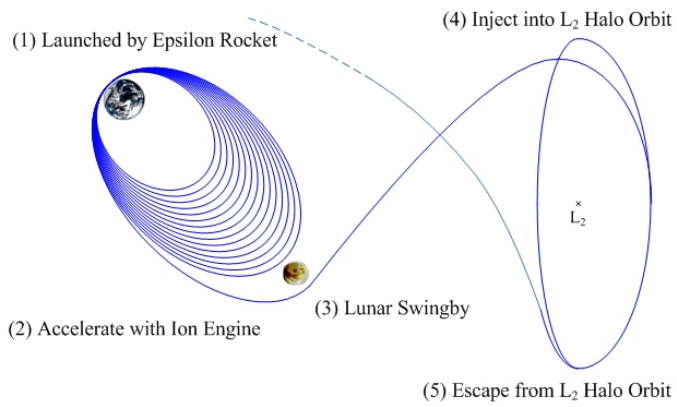
DESTINY itself is an engineering experiment probe which destines L<sub>2</sub>. However, its mission profile is naturally applied to lunar missions and escape missions by forking the profile at the lunar encounter. Moreover, the spacecraft's high astronautic performance makes its application to other launch method attractive, such as dual launch with GEO satellite or another deep space probe. The significance of DESTINY from the point of its opening new opportunities for low-cost deep space mission is discussed in the presentation as well.

Keywords: Small Science Satellite, Technology Experiment, Deep Sapce Exploration, DESTINY

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## Planetary Exploration in a Coming Decade Activity: From 2nd to 3rd Stage

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Future Planetary Exploration Working Group of Japanese Planetary Science Society is discussing planetary explorations that will be strongly supported by this community. Then we started "Planetary Exploration in a Coming Decade" activity last year aiming to organize a new mission to be launched between 2017 and 2027. The second stage of the activity is ending after this session. Each proposal of the second stage will be reported in Yu-Sei-Jin journal. Then the third stage starts to reinforce technical aspects of the proposals.

Keywords: Planetary Exploration

## Mission proposal for asteroid Phaethon

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A mission proposal for asteroid Phaethon and related asteroids is presented.

Keywords: Asteroid, Phaethon, comet, Solar system evolution, Geminid Meteor Stream

## Return to Itokawa: Impact experiment on the rubble-pile asteroid

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Asteroid Itokawa is a small rubble-pile body once explored by Hayabusa-space craft, and the only asteroid that the surface sample was returned to the Earth. So, we now accumulated a lot of scientific knowledge related to this asteroid, but simultaneously the more questions are raised and waiting to be solved. Then, we propose a new possibility for the exploration of Itokawa from the point of view of re-exploration and an impact experiment on the asteroid surface.

The purpose of this mission is to deeply understand the scientific knowledge that we obtained from Hayabusa mission by means of the re-exploration of Itokawa. There is a huge advantage for the re-exploration of Itokawa compared to the exploration of the first arrival asteroid. Because we already have a detail information of geography and gravity field on Itokawa, so we can select and optimize instruments for the measurements especially for Itokawa. In this re-exploration of Itokawa, we propose an impact experiment on the surface in order to clarify the impact physics on asteroid with very low gravity field and to study the internal structure of a rubble-pile body by means of this active exploration.

The impact experiment will be conducted by using a improved Small Carry-on Impactor (SCI) developed for Hayabusa 2 space-craft. In the case of Itokawa, we already know the surface geography, and so we can determine the impact point before the exploration exactly. The improved SCI should have a self controlled system for its posture and will impact the exact point with the precision of 10m. In this moment, Muses sea is the best candidate for the cratering experiment by the SCI to study the effect of gravity on the cratering process and construct a mechanical model of the subsurface layer of rubble-pile body. This result will be an anchor for the future impact study and it should be referred to extrapolate the laboratory study to the planetary scale impact.

The artificial impact crater by the SCI will be observed by a sub-satellite for in-situ observation equipped with cameras, a dust counter and a dust LIDAR. We also plan to use a penetrator equipped with a seismometer to observe a seismic vibration by the SCI impact. The three penetrators will be set on Itokawa surface to construct a network of the seismometers and they are used to analyze the internal structure of Itokawa and to obtain the information of dynamics of granular materials under very small gravity field. In addition to the seismic observation, a radar investigation will be very effective to look through the interior of Itokawa. The sample return from Itokawa was already successful in Hayabusa, but the amount of the sample was not enough large to measure the physical properties of bulk sample. Therefore, we try to recover the sample from Itokawa surface for the study of the bulk physical properties, e.g. pebbles of Muses sea.

According to these measurements, we will construct a physical model of planetesimal, which is a virtual body in the solar nebula with an internal structure like a rubble-pile body.

Keywords: Itokawa, re-exploration, Impact experiment, Hayabusa

## Exploration of Trojan asteroids and interplanetary dust complex by a solar sail mission

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”Asteroids couldn’t grow up to be planets. Why?” This is one of the most fundamental and important question in planetary science. In order to answer this question, we need to study two problems, i.e.;

- \* Why did the collisional growth of planetesimals turn into disruption? Jupiter formation caused the transition?
- \* The effect of compositional variation of the planetesimal across the ”snow line”

Therefore, Trojan asteroids are key objects, but traditional spacecraft cannot reach them without onboard radioisotope thermoelectric generators. In this presentation, we propose a solar sail mission to Trojan asteroids. In-situ and remote sensing observations of Interplanetary dust particles (IDPs) will be made en route. The ”clear sky” free from IDPs beyond the asteroid main belt would enable us to observe the cosmic infrared background emission from early universe. This mission provides an ideal synergy of planetary science and astronomy.

Keywords: Solar sail, asteroid, comet, Interplanetary dust

## Elemental analysis instrument for landed lunar and planetary explorations: Laser-induced breakdown spectrometer (LIBS)

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In general, lunar and planetary explorations are carried out through the processes of remote sensing by orbiting satellites, in-situ observation by landers and rovers, sample return, and manned exploration. Lunar and planetary explorations of each country will shift to a sample return phase. However, the results of past remote-sensing explorations show that moons and planets in the solar system have complicated and various surfaces. This clearly indicates that we cannot know the origin and evolution of a planetary body from a sample that is recovered from anywhere on it. The necessity of in-situ observations by landing to multiple sites and the importance of understanding the geological context of landing sites are suggested from the experience of the past planetary explorations, especially the landed explorations on Mars. Therefore, a landed geological exploration as a prior phase of sample return is indispensable. In such a case, a wide range of movability by a rover with a quick and efficient elemental analysis method is necessary. Laser-induced breakdown spectrometer (LIBS) is an elemental analysis instrument that is appropriate to such lunar and planetary surface explorations.

The measuring principle of LIBS is as follows: Samples are irradiated with pulsed laser beams in order to generate plasmas of a small amount of a sample. When atomic and ionic species excited in the plasmas are deexcited, the emission of lights occurs according to the difference in energy levels before and after the deexcitation. These lights are measured with a spectrometer as emission lines on spectra. The wavelength of emission lines is unique to each element, and the intensity of emission lines is correlated with the elemental abundance. Both qualitative and quantitative analyses, such as elemental abundance determination and mineral classification, are carried out by analyzing the acquired spectra.

LIBS has several advantages such as (i) capability of remote analysis (up to ten meters or more depending on laser intensity), (ii) rapid data acquisition (a few second to a few minutes), (iii) ability to analyze almost all elements including light elements, (iv) high spatial resolution (several tens to several hundred of micrometers), (v) unnecessary of sample preprocessing, and (vi) unnecessary of an radiation source. On the other hand, LIBS have a weak point of slightly worse determination precision than other elemental analysis methods usually used. However, recent studies show that the use of multivariate analysis methods such as partial least squares regression as a spectral analysis method improve the determination precision.

LIBS is basically composed of a laser, a spectrometer, and optical system. Various configurations are possible according to the size of a landing explorer (a rover or a lander) or the objective of an exploration. For example, "Measured-distance-variable remote LIBS", in which focusing of both the laser beams and emitted lights are conducted through a measured-distance-variable telescope, can measure distant samples. Rapid data acquisition for multiple samples is possible without moving a rover or a lander. Since this configuration requires a telescope with large diameter lens, a drive mechanism for the telescope, and a laser with high output power, the size and weight of this type of LIBS tends to be large. "Measured-distance-fixed near LIBS" measures samples with small laser and simple optical system equipped on a robot arm of a rover or a lander. Since neither a telescope with large diameter lens nor drive mechanism for the telescope are needed, this type of LIBS can be small and lightweight.

LIBS exerts its capability when it is equipped on a rover. Rapid analysis of distant samples makes the selection of interesting sites where a rover moves to possible. In a future sample return mission LIBS will be a suitable instrument for searching appropriate samples to recover.

Keywords: elemental analysis, geological exploration, planetary exploration, LIBS, Moon, Mars

## Operataion test of LIBS onboard lunar and planetary rover

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We are developing Laser Induced Breakdown Spectroscopy (LIBS) instrument for lunar and planetary exploration. We manufactured a prototype model in 2011. It is composed of a high-energy pulse laser, optics for focusing light at the surface of the target, an image sensor, and spectrograph. We attended the field roving test of one of the prototype of lunar and planetary exploration rover, Micro-6 at the top of Mt. Aso in Kumamoto from 7 to 9 in November, 2011. We used a prototype LIBS model without a pulse laser to demonstrate the performance of auto-focus mechanism because there are many tourists and we had to avoid injuring their eyes without eye-safe glasses. After that, we performed the test with a high energy pulse laser with mini-rover in the room in Sagamihara campus of ISAS/JAXA. We confirmed that it is difficult to install the LIBS on the gimbal at the top of the mast of the rover because of its weight and the data rate is too low to control our prototype. In this presentation, we report our test result and introduce the renewed design of LIBS for lunar and planetary exploration.



## Development of an in-situ K-Ar dating instrument for landing planetary missions

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We propose an instrument that conducts the in-situ age measurement of rocks during landing missions. The absolute age of a geological unit is one of the most important information for the planetary science. However, the absolute chronology of Mars is poorly constrained due to the lack of directly dated samples. The uncertainty is as large as 1 billion years, preventing us from quantitative understandings of the Martian history. In order to obtain accurate and precise age, sample return missions are of course ideal but such a mission must face many technical challenges and huge budget as compared to sending a robot to the planet. Additionally, sampling place will be limited because of the cost. Therefore the main goal on Mars mission is to calibrate absolute chronology by in-situ age measurement on Mars.

Our interest also includes future lunar landing missions. One of the most important objectives is that contribution to the sample-return mission from the Moon because such a mission is more realistic than that of Mars. Our instrument will be able to provide information whether a rock underwent resetting event after its formation. We can choose primitive rock samples on the Moon, maximizing the scientific value of the sample return mission.

The instrument determines the K-Ar age of rock samples on a rover in the following way. Laser-induced breakdown spectroscopy (LIBS) and quadrupole mass spectrometry (QMS) are coupled with each other to measure K and Ar, respectively, and it is named LIBS-QMS system. The instrument consists of a vacuum chamber, pulsed laser, an X-Y stage, a CCD camera to observe the measured site, a spectrograph, a QMS, a getter to purify the extracted gas, and a vacuum pump, which is unnecessary for lunar missions. An outstanding feature is that the spot analyses using laser beam enable isochron measurements, which improves the accuracy and precision of age determination.

In order to establish the K-Ar in-situ dating instrument, the following items need to be achieved: (1) improving the accuracy of K measurement by overcoming the matrix effect, (2) improving the detection limit for both K ( $\sim 1000$  ppm) and Ar ( $^{40}\text{Ar} \sim 10^{-11}$  cc,  $^{36}\text{Ar} \sim 2 \times 10^{-11}$  cc) by an order of magnitude, and (3) inventing proper sample handling system, that is, how to pick up rocks, put them into the vacuum chamber, and how to measure them.

We show the current strategy to resolve such issues. First, the matrix effects are shown to be removed to some extent by the multivariate analytical techniques (e.g., partial least squares regression method, neural network analysis). Such statistical techniques will be introduced to our signal processing method. Secondly, we have improved the experimental conditions by optimizing the light collection system in order to enhance the observed intensity of K emission lines. We also replaced our previous detector system, which consisted of a 75 cm spectrograph and an ICCD camera, to a compact spectrograph ( $\sim 500$  g in weight) equipped with an ordinary CCD detector. Our preliminary experimental results show that the K emission lines from  $\sim 4000$  ppm K<sub>2</sub>O sample are detected by such spectrographs. Improving the limit of detection by an order of magnitude seems to be possible. To improve the detection limit of Ar, the conditions of laser beam (e.g., beam diameter, pulse energy, and beam profile) are required to be optimized. Reducing the blank level of QMS is essential as well. We are now building an oil-free exhaust system. The sensitivity of QMS will be enhanced by reducing the volume of the vacuum system. Finally, the sample handling procedures will be considered with some experts in this area. We are going to establish our method in 2012 and build a compact breadboard model by the end of 2013.

Keywords: In-situ dating, K-Ar dating, Landing mission, LIBS-QMS

## Equipments for life search exploration on Mars

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Among the planets and giant satellites in our solar system, the characteristics of Mars are most similar to those of Earth. This may suggest that it may be possible for life similar to terrestrial life to arise and to survive on Mars.

Here we propose a new life detection project on Mars to search for methane-oxidizing microbes by fluorescence microscopy combined with amino acid analysis and mass spectrometry. We propose to search for cells from a depth of about 5 - 10 cm below the surface, which is feasible with current technology. Microscopic observation can be done using low mass equipment with low electric power consumption, and has the potential to detect single cells. The subsequent analysis of amino acids will provide the information needed to define the origin of the cell.

Keywords: Mars, Life search, Fluorescence microscope, Amino acid analysis, Mass spectroscopy, Methane oxidizer

## Investigation of Martian surface and interior structure by penetrator probe

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We propose a mission to investigate the Martian surface environment and internal structure by multiple instrumented penetrator probes. The Mars penetrator has two parts, a slender forebody and finned afterbody, connected by an umbilical cable. At the impact, the forebody penetrates into the surface material, whereas the afterbody remains on the surface with a flared terra-brake. As for scientific instruments, a slightly broadband seismometer, thermal conductivity sensor, gamma-ray sensor, and water-detection sensor are housed in the forebody together with most of the electronics parts and a battery package for power supply. A meteorological sensor package and a radio source for geodetic experiment are installed in the separated afterbody. For the purpose of a long-lived geophysical observation, solar panel arrays might be stuck on the facets of flared structure. In addition, the atmospheric density, pressure and temperature will be derived using entry and descent data, and then, an accelerometer profile will be used to determine the impact velocity, depth of penetration and the mechanical properties of surface layers at impact site. The four identical penetrators will land within 100 to 300 km of each other on the Elysium region or Tharsis province; the former is assumed to be most recently active in volcanism, the latter is located in a vast fault zone. Both the two candidate sites have not yet been landed by soft-landers. Primary goal is to demonstrate the penetrator technology that will enable future science missions and, in particular, geophysical network observations. Secondary goal is to determine the seismicity of Martian interior as well as meteoroid impact flux. Third, a continuous monitoring of surface environment(atmospheric temperature, pressure and magnetic field) is essential for the analysis of seismic data and for the advanced design of future geophysical instrument package. After separation of penetrators, the orbital spacecraft will fly over daily and communicate with each penetrator probe for data-relay and measurement of libration parameters of Mars. And also, An impact monitoring camera onboard the spacecraft would detect a number of impact craters and landslides occurred during the mission operation and we could make good use of imaging data in 1~10 meter scale as known locations of Mars quake foci in order to investigate the crust/upper mantle structure.

Keywords: Mars, Surface environment, Internal structure, penetrator

## Development of optical seismometers for observations at extreme environments

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Seismic observation is useful for investigating interior structure of the Moon and planets. Especially for global structure including deep structure, broadband seismic observation is required. Although short-period seismometers have been used for seismic surveys in the Moon and Mars, broadband seismometers on the surface environment would open up new interior information. Similarly on the earth, broadband seismometers in the deep borehole enable us to observe near a seismic region at low background-noise environment. Hence, broadband seismometers for extreme environment in temperature, cosmic rays, limited power/space, and impact by launch/installation would be essentially required for future seismic surveys. For this purpose, we have been developing optical seismometers that can be used at extreme environment; a laser interferometer, which can operate in such environment, senses pendulum motion with high sensitivity.

We developed a prototype (dimension: W200mm H210mm D115mm) and have confirmed its stable operation, broadband performance (1mHz-50Hz), and self noise level. Optical fibers are used to transmit laser light. In parallel, we have carried out a high-temperature test for the laser interferometer, and confirmed normal operation up to 290 degrees centigrade.

Currently, we have started making a smaller model and developing an automatic operation system. Because optical sensors can be operated in various environments with flexible configuration, they are also useful for planetary explorations on Venus, Mercury, icy satellites of outer planets at extreme temperatures.

Keywords: seismometer, broadband, planetary exploration, laser, interferometer