Thermal Infrared Imager TIR on Hayabsua2 and Its In-Flight Performance using Earth-Moon Thermal Images.

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Thermal infrared imager TIR is a remote instrument on Hayabusa2 sample return mission from C-type near-Earth asteroid 162173 Ryugu, organized by Japan Aerospace Exploration Agency (JAXA) [1]. The instrument is based on the uncooled micro-bolometer array inherited from the Longwave Infrared Camera LIR on Akatsuki Venus Orbiter [2]. TIR is to observe thermal emission off the asteroid surface, and investigate its thermo-physical properties. We report here the results of in-flight performance of TIR, especially for observations of Earth and Moon.
TIR consists of the sensor unit (TIR-S) and the power supply unit (TIR-AE), along with the digital electronics (DE) for image data processing and the interface for telemetry and command. A couple of images are taken with its shutter open and close so that an effective thermal image is consequently derived by subtraction of these two images [3].
TIR covers its wide temperature from 150 to 460 K, meaning all the sunlit areas of Ryugu, and even the shadowed areas if the thermal inertia of the surface is higher than 50 [tiu = J m^{-2} $s^{-0.5}$ K^{-1}]). Field of view of TIR is 16.7° x 12.7° in horizontal and vertical directions with 328 x 248 effective pixels, with IFOV of 0.051° per pixel. This corresponds to about 17 m per pixel from the Home Position, 20 km altitude from asteroid surface. The closest view by TIR is about 1cm from the 10 m altitude during the final approach to touchdown [3].
Performance of TIR has been checked almost monthly. We controlled its temperatures by adjusting the setting points of Heater Control Electronics HCE of Hayabusa2 to investigate temperature dependency of TIR images. TIR observed the deep sky during the checks. TIR images have peripheral brightening due to thermal emission from the hood and optics of TIR. We found the lower detection temperature limit of TIR is about 150K. The effect of peripheral brightening is thoroughly reduced from TIR images by subtracting a deep sky image taken at the same temperature settings. TIR was mounted on the +Y panel of Hayabusa2 spacecraft and pointed to -Z axis. The -Z axis alignment of TIR was surveyed using the images of Earth and Moon taken before and after the Earth swing-by. Alignment of TIR in -Z axis is checked relative to that of spacecraft, and proven within 1 or 2 pixels (0.05° or 0.10°) shifted in horizontal and vertical directions [4]. It was the unique opportunity for TIR to observe the Earth and Moon, which are the only targets with known thermo-physical properties in space before arrival at Ryugu. TIR images were taken a few minutes before the Optical Navigation Camera (ONC-T) to compare TIR and ONC-T images. In the Earth's images, Australian Continent is hotter than the surrounding ocean by 10 to 20 °C, the Antarctica is cold at around -45 to -40 °C, the southern Indian Ocean is about 0 °C. Clouds are about -45 to -30 °C. The Moon was imaged only 5 pixels in diameter, but the highest temperature can be estimated as 60 to 70 °C for the area at

medium latitude. This is consistent with the estimated value for the area. The observations of Earth and Moon by TIR show that the surface temperatures are consistent with the estimated values. Thus we believe that thermal images by TIR are expected to make an essential contribution as planned for the exploration of asteroid Ryugu.

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Keywords: Hayabusa2, asteroid exploration, thermograph, Thermal Infrared Imager, Earth Swing-by, thermal inertia

Image and database browser for TIR on Hayabusa2

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1
Introduction: Hayabusa2 was launched to an asteroid, Ryugu. The spacecraft will arrive at the asteroid in 2018 [1]. Hayabusa2 TIR (Thermal Infrared Imager) [2] science team should complete preparations of analysis. The preparations include development of TIR image viewer and establishment of TIR calibration procedures. Those should be ready until the rendezvous for analyzing observation data. This study is categorized into fields of computer graphics and big data analysis in computer science. This study develop image and database browser. This study has developed two sub systems. One is thermal image viewer. Another is thermal image database for calibration. Thermal calibrations exist 2 ways that using calibration curve and using interpolation based on near parameters by calibration database. Although thermal image viewer exists such as ParaView [3], those viewers don’t have calibration system. The former way uses calibration formula such as Arai (2015) [4]. The way converts easily digital number to temperature. On the other hands, lacking precision of the way depends on a calibration formula, because the way based on an approximation. The latter way uses same method such as big data analysis. The way finds matching data or near parameters data from a large amount of data. The way needs a database function. That is thought able to calibrate precisely, but the way requires high calculation costs. The way is a key to develop new type of viewer. Therefore, this study has development of a system of involving viewer and a database for calibration. The system is developed from scratch. Goal of this study is development of software that visualizing TIR exploration data and getting TIR ground test data for calibration. TIR data consists of TIR image and ancillary data. The ancillary data has target information, optical information and environment information.
2
Requirements: Required functions were decided based on hearing with Hayabusa2 TIR science team. The requirements were divided into 4 items.
-Loading TIR data
-Displaying TIR image and 3D model
-Getting TIR data for a calibration
-Database for ground test of TIR
3
Development Environments: The environments can develop by open source.
4
System Design: The system has 6 modules. Those modules are built into 4 components.
Components
-User Interface
-Processing
-Database
-Converting
Modules
-Loading TIR data

-Displaying TIR image
-Converting
-Database browser
-Displaying Visualization Toolkit file
-Display 3D model.
5
Calibration database: Calibration database stores TIR data. The database consists thermal image table and pixel information table. This data is obtained by ground test of TIR in JAXA. This study refers to Kuwano (2016) about pixel information table [5].
6
Results: This study considered Trade-off and User feedback.
7
Demonstration: We have a demonstration of this system in this presentation.
8
Discussion: It is developed in this study that the system suitable for analyze. The system should be improved on.
9
Conclusions: This study has developed the system. The system displays TIR image and ancillary data. This system satisfies all requirements.
10
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Keywords: Hayabuse2, Database, TIR

Curation works for the Hayabusa samples and development for Hayabusa2 sample curation facility

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Hayabusa spacecraft successfully returned its reentry capsule including regolith samples of S-type asteroid Itokawa to the Earth in 2010 [1, 2]. Their preliminary examinations revealed that they are similar to equilibrated LL chondrite [3]. JAXA astromaterial sample research group (ASRG) conducted international announcement of opportunity (AO) for Hayabusa-returned samples twice from FY2012 to FY2013. With the two AOs, 32 research proposals have been selected for sample allocations and 112 particles have been distributed to them [4]. Based on results of their researches, it is figured out that space weathering rims on regolith particles are less developed in those from the first touchdown place than the second one [5] and the gas retention age of three Itokawa particles was determined as 1.3 billion years by ^{40}Ar-^{39}Ar dating, which is considered to reflect the age just before or during the catastrophic impact event on the precursor body of the present asteroid Itokawa [6]. The ASRG conducted the 3rd international AO for Hayabusa-returned samples in FY2015. 12 research proposals were selected for sample allocation in Jun 2015, 44 particles for 11 proposals have been distributed until Jan 2016 as we started their distributions in Aug 2015. We are now planning to start international AO in which we will always accept research plan in FY2016. Simultaneously, the ASRG has developed a specification of curation facility for returned samples by Hayabusa2, which was launched in Dec 2014, under the supervision of the specification developing committee for Hayabusa2 sample curation facility [7]. Hayabusa2 will reach C-type asteroid Ryugu in 2018, execute remote-sensing observation, impact crating experiment, and three-times sample collections in a year and half operation there, and return the collected samples to the Earth in Dec 2020. In the committee, we are discussing performances and functions of instruments and facilities in order to start their functional checks and rehearsals for returned sample acceptance in FY2018. We are now considering to equip a function to recover and preserve a certain amount of samples from the sample catcher in vacuum condition. We consider that we will start construction of facilities for Hayabusa2 as early as FY2016.

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Keywords: Hayabusa2, Sample return mission, curation, Itokawa, Ryugu, Hayabusa

Current Status of Hayabusa2 Landing Site Deliberation

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Hayabusa2 is scheduled to arrive at the C-type asteroid 162173 Ryugu on July 2018. During its 18-month stay, Hayabusa2 will sample surface materials at three different locations on the asteroid (Yoshikawa et al., 2014). To maximize the scientific gains of Hayabusa2 mission, it is important to select the landing sites from scientific aspects that are derived from integration of remote sensing data obtained by on-board instruments, ONC, NIRS3, TIR, LIDAR, and MASCOT, and laboratory experiment data obtained by using meteorites and simulant of asteroidal materials. Therefore, the Interdisciplinary Science Team which draws the general picture of a scientific scenario of Hayabusa2 (Kobayashi et al., 2014) newly organized four working groups in 2014. The main purpose of these WGs is to select the best landing site by integrating remote sensing data and meteoritical knowledge, and is to expand planetary science into new research fields via the WG process.
Meteorite WG: The primary purpose of this WG is to identify the surface of Ryugu with one of the meteorite groups. Previous studies show that many carbonaceous chondrites are petrologically heterogeneous in a mm-cm scale. Meter-scale observation of the entire surface obtained by Hayabusa2 would contribute to understand the formation history of C-type asteroids including asteroid Ryugu. In order to constrain the meteorite group using the remote sensing data, petrologic variations observed in different meteorite groups and those within a group are being discussed. Brecciation, secondary alteration, and space weathering effects on the asteroid surface are also considered in collaboration with the other WGs.
Secondary alteration WG: We have proposed the following 3 candidates as scientifically valuable samples on Ryugu; (1) major components, (2) primitive materials (here after, 'primitive materials' are supposed to be materials that were experienced the least secondary alteration on the asteroid), and (3) others (e.g. exotic material). Firstly, we discussed the detailed spectral characteristics for identification of the primitive materials on the asteroidal surface using data acquired by the on-board instruments. Reflectance spectra of the primitive materials should show low albedo, no/weak 0.7 and 1 um absorptions suggesting presence of hydrous minerals and anhydrous silicate respectively, and a clear absorption-band at 3 um caused by presence of hydrous phases. However, the spectral features of asteroids are complex since they depend on several parameters. Further accumulation of reflectance spectra for various groups of meteorites will be required. The other candidates will be examined as well.
Volatiles WG: Searching organic compounds from the asteroid surface is one of the significant goals of Hayabusa2. In particular, organic carbon contents could be an indicator for a primitive asteroid. For example, the contents of insoluble organic matter (IOM) and total organic carbon (TOC) from CM, CR, and Tagish Lake chondrites negatively correlate with the albedo features at the wavelength of 0.55 and 0.39 um in their reflectance spectra (Hiroi et al., 2016), respectively. These correlations appear to be related to the aqueous alteration degrees. TOC values are superficially higher in the aqueously altered chondrites. To be more accurate, we propose that the albedos are the better indicator reflecting the ratio of IOM to soluble organic matter (SOM).

Further laboratory experiments must be carried out in order to evaluate the degrees of thermal metamorphism and space weathering.
Grain size WG: The possible methods for determination of the asteroidal surface condition have been organized so far. We continue discussion about the surface condition determination by integrating data from several on-board instruments. In addition, the influence of grain sizes on spectral feature will be evaluated.

Keywords: Hayabusa2, Interdisciplinary Science Team, landing site

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Earth-moon images captured by Hayabusa2 visible cameras during Earth swing-by

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JAXA's Hayabusa2 completed an Earth swing-by on December 3th of 2015. During this opportunity, we photographed both Earth and Moon with three optical navigation cameras (ONC-T, W1 and W2). Since this was the last opportunity to observe extended light source before reaching the target asteroid Ryugu, the obtained images are extremely important for calibration of our cameras. In this paper, we present the Earth-Moon images and preliminary analysis results.

The Effect of Rotation Period on Slope Distribution on Asteroid Itokawa

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Asteroids 25143 Itokawa was visited by the spacecraft Hayabusa and its detailed surface was unveiled. Demura et al. (2006) reported that Itokawa surface is divided into rough highlands and smooth low lands. Rough areas are covered with lots of boulders. Meanwhile, there are few boulders in smooth areas. It might be the result of regolith migration by seismic shaking (Miyamoto et al. (2007))
Itokawa has very steep slope areas especially on the neck region. “Slope” is defined as the separation angle of a gravity acceleration vector and a normal vector of a surface facet.
Non-spherical body like Itokawa has an asymmetric gravity field. Polyhedron model, which was studied in Werner and Scheeres (1997), is an effective way to calculate such an asymmetric gravity field of a polyhedron with homogeneous density. We calculated the surface gravity field and slope distributions, giving Itokawa shape models, observed rotation period (12.1324 hour) and the bulk density (1.95 grams per cubed centimeters). We found that there are many steep slope areas over 30 degrees in the neck region of Itokawa. Such a steep slope looks like unstable.
Change of rotation period is known as YORP effect by solar radiation. As a rotation period changes, a surface gravity field and a slope distribution also change. This phenomenon makes a strong effect on Itokawa’s history of reconfiguration and surface terrain formation in hundreds of thousand years time span. This time, we calculated the slope distribution with different rotation period (4h, 6.5h, 9h, 12.1324h, 18h, 24h). It showed that faster rotation can change surface gravity and reduce slope.
One of possible scenarios for Itokawa formation is that Itokawa rotated much faster before and surface topography was formed then. After that, the spin rate may have been decelerated by YORP effect.
S. C. Lowry et al. (2014) studied that observed light curves of Itokawa and simulation of YORP effect and inferred interior density distribution. We expect to simulate the surface gravity with heterogeneous density and make a restriction on internal structure of Itokawa.

Keywords: Asteroid 25143 Itokawa, Gravity field, Slope, YORP effect

Asteroids as Records of Solar System History

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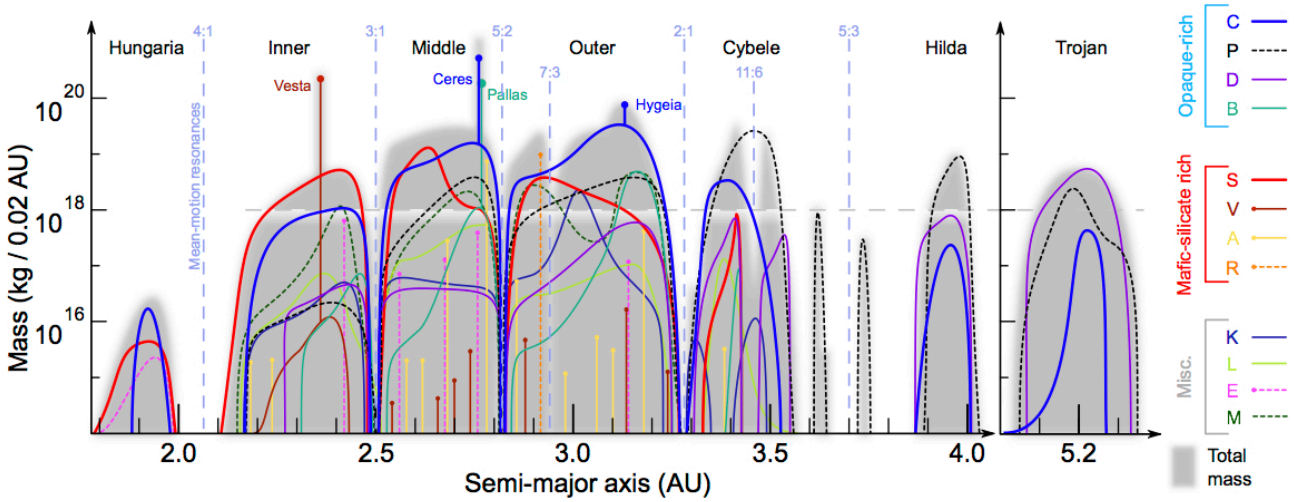
Asteroids and other small bodies are markers, like tiny beacons, relaying information about the initial temperature and composition conditions of our Solar System revealed by their surface compositions. The Solar System's evolution may also be determined from the scattering record of these bodies. Today we are armed with major advancements from the past decade that have revolutionized the field of asteroids in areas such as discovery, physical characterization, meteorite links, and dynamical models. Based on tens of thousands of measurements from the Sloan Digital Sky Survey, in this talk I present a new compositional map of the asteroid belt that reveals a greater diversity of asteroids as a function of size and distance and discuss these results in the context of Solar System formation and evolution.

Keywords: asteroid, composition, solar sytem



Fluid flow in hydrous asteroids induced by H_2 gas pressure

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Physicochemical models on thermal history associated with material evolution of hydrous asteroids have been explored by many authors (e.g., Grimm and McSween 1989; Cohen and Coker 2000). A few models included fluid flow in these bodies to reproduce the characteristic oxygen isotopic compositions of aqueously altered meteorites like CM and CI chondrites (e.g., Young 2001; Palguta et al. 2010). These fluid flow models predicted convective or exhalation flow induced by temperature gradient or vapor pressure. Although these models involved hydration reactions, gas phases such as H_2 produced by the reactions were not taken into account.
Here I present a model on fluid flow in hydrous asteroids considering H_2 gas generated by oxidation of metallic iron. Since H_2 gas pressure in hydrous asteroids is inferred to be hundreds of bars from the amount of metallic iron in primitive chondrites, steep pressure gradient occurs between the surface and interior of the asteroids. The model is 1D spherically symmetric and includes thermal conduction of heat generated by ^{26}Al decay, phase transition of water/ice, a simplified aqueous alteration reaction, and fluid flow. I assume that the asteroids accreted 2.7 Myr after CAI formation, resulting in the initial $^{26}Al/^{27}Al$ ratio of 3.7×10^{-6}. The velocity of fluid flow is derived from the Darcy's low. The radii of the asteroids range from 30-100 km. The initial temperature is 173 K, and the surface temperature is fixed to this value. The asteroids initially consist of 70 vol% rock, 5 % water/ice, and 25 % void space. When liquid water is present, the rock reacts with water and 90 % of the consumed water is assumed to convert to H_2 gas until metallic iron is completely oxidized.
The results of the simulation suggest that fluid (H_2 gas and liquid water) flows outward soon after ice melts and water reacts with rock. However, water stops flowing ~8 km below the surface because temperatures there are lower than the freezing point of water. Then an icy shell forms near the surface, and liquid water accumulates just below the icy shell. As a result, water heterogeneously distributes throughout the asteroids in spite of its initially homogeneous distribution. Water consumed by the alteration reaction amounts to ~1.7-3.1 vol% around the center of the asteroids and to 5.5-16 % below the icy shell, depending on the asteroid sizes. The peak temperatures range from ~800 K around the center to ~370 K in heavily altered regions. These combinations between peak temperatures and alteration degrees are consistent with those inferred for CO and CM chondrites. This may imply that CO and CM chondrites originated from the same parent body, suggested from their oxygen isotopic compositions forming a single regression line in an oxygen three-isotope plot.

Keywords: fluid flow, hydrous asteroids, hydrogen gas

Experimental study on compression property of granular material

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Porosity structure inside a planetary body and of surface regolith plays important role in collisional and thermal evolution of the body. The porosity structure is changed by presence of rocks, seismic shaking, thermal evolution, and self-gravity in particular. Porosity structure caused by soil pressure due to self-gravity gives an initial, most-possible porous structure of the body consisting of granular material. Therefore, understanding compression property of granular material is necessary. Compression properties of granular material should be controlled by various parameters such as initial porosity of granular bed, composition, size distribution, and shape of constituent particles. Moreover, the surface energy of constituent particles thought to become 100 times larger in vacuum than in atmosphere (Kimura et al. 2015). The interparticle force, and consequently the compression properties, depends on the surface energy. Therefore, general formula for the compression property of granular material in various environments is required to estimate the porosity structure of planetary bodies.

An empirical formula to estimate the initial porosity of granular bed consisting of monodisperse particles deposited by gravity was introduced by Kiuchi and Nakamura (2014) based on the ratio of interparticle force and gravity. However, this formula is only applicable to the uppermost layer of granular bed because the granular bed at some depth is compressed by soil pressure. During the compaction process of granular bed, the porosity of granular bed is decreased by rearrangements of constituent particles and this rearrangement mechanism changes with coordination number of constituent particle. When the coordination number is less than 6, the constituent particles are rearranged by rolling. When the coordination number exceeds 6, they are rearranged by sliding. The coordination number increases as the porosity decreases. The coordination number reaches 6 when porosity is ~0.7 (Wada et al., 2011).

We conducted compression experiments of various kinds of samples. Each sample has different composition and size distribution. Main compositions of the samples are Al_2O_3 and SiO_2 and the particle size is smaller than 100 μm. We sieved these samples into cylindrical container and the top part of the bed over the height of the container was leveled off. Then we compressed the sample by compressive testing machine. The applied pressure was ranged from 10^4 to 2×10^6 Pa.

The initial porosity of the granular bed was different for different samples and it was in the range of 0.54-0.86. We compared this result with the formula introduced in Kiuchi and Nakamura (2014). We found that this formula can estimate approximate porosity of granular bed constituted by polydisperse particles if we adopt the median diameter of the particles as representative particle diameter. It was shown that the slope of compression curve becomes shallower as the frictional force between particles increases in the range of the pressure between 10^4 and 2×10^6. In this range, porosities of samples are less than ~0.7. Size distribution width of sample affects compression properties too and the samples with wider size distribution are compressed easier (Omura et al., ISTS, 2015).

We conducted new compression experiments. We expanded the pressure range to lower than 10^2 Pa and we found that compaction process of granular bed is divided into three regimes: (1) Pressure is lower than the strength of granular bed accordingly the granular bed isn't compacted. (2) Granular bed is compacted but the decrease in porosity is gradual. (3) The porosity decline-rate becomes larger than the regime 2. We will further investigate how these boundaries are determined and will present the results.

Keywords: Small body, Porosity, Internal structure, Granular material

Thermal Modeling of Comet-Like Asteroids

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Recent analysis on asteroidal thermophysical property revealed that there is a tendency that their thermal inertia decrease with their sizes at least for main belt asteroids. However, little is known about the thermal properties of comet-like bodies. In this work we utilized a simple thermophysical model to calculate the thermal inertia of a bare nucleus of comet P/2006 HR30 (Siding Spring) and an asteroid in comet-like orbit 4015 Wilson–Harrington from AKARI observation data. It is also shown that the determination of their thermal inertia is very sensitive to their spin vector, while the diameter is rather easy to be constrained to a certain range by combining multi-wavelength observational data. Thus, we set diameter and hence the geometric albedo as fixed parameters, and inferred the spin vector and thermal inertia of the targets. Further detailed analyses on these cometary bodies will shed light on our understanding of the detailed surfacial characteristics of them.

Keywords: Thermal model, Asteroids, Thermophysical model

MONITORING OBSERVATIONS OF THE JUPITER-FAMILY COMET 17P/HOLMES DURING ITS 2014 PERIHELION PASSAGE

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Comets are the most pristine reservoir of the materials left over from the formation epoch of the solar system. When they are heated and expel this ancient material in their orbital motions around the Sun, we can have the opportunity to decipher the primitive information which have buried underneath the cometary surface for a long time. Herein, we present a brief overview of our observational results of a Jupiter-Family comet, 17P/Holmes, which underwent the historic outburst in 2007, to investigate its secular change in activity during 2014 perihelion passage. We performed the monitoring observation over two years, welcoming its first perihelion passage since the 2007 outburst. We analyzed the imaging data taken over two years, and found that there is a strong asymmetry of cometary activity with respect to the perihelion. Compared to the values taken right after the 2007 outburst, our results present a dust-production rate that has been utterly quenched by about five orders of magnitudes and is rather similar to that of pre-outburst inactive phase. We also found that the secular evolution of the fractional active area over the cometary surface had drastically dropped by about two orders of magnitudes in only one orbital revolution around the Sun. All of our results indicate that 17P/Holmes has entered upon an inactive phase far more rapidly than the prediction of the previous researches, and from this we conjecture that a surficial dust layer (~7 –10 cm in depth) of the comet play a dominant role as an insulator of sublimation of subsurface water ice from the solar irradiation.

Keywords: comets, 17P/Holmes

DESTINY+: A Technology Demonstrator for Deep Space Exploration

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DESTINY+, which stands for “Demonstration and Experiment of Space Technology for INterplanetary voYage,” is a mission candidate for the next space science small program.
DESITNY+ is a high performance deep space transportation system whose maximum delta-v capacity is 5km/s, and maximum payload mass is 200kg. DESTINY is based on the previously developed small scientific standard satellite bus system, and extended by five novel technologies. The key technologies to realize DESTINY+ are, the large scale ion engine, the ultra-light weight solar panel, advanced thermal control devices, novel mission & orbit design, and small & high specification newly developed bus components.
DESITNY+ also demonstrate multiple fly-by explorations of near earth objects (NEO) by using instruments on DESTINY+ mother ship and its daughter probe “PROCYON mini”. The first target NEO is one of the most unusual comet-asteroid transition bodies, 3200 Phaethon, which has dust tails. In this paper, we present the outline of mission plan, the system design, and key technologies of DESTINY+.

Keywords: DESTINY+, PROCYON-mini, Phaethon

DESTINY+: Phaethon fLyby with reUSable probe

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Asteroid (3200) Phaethon is a parent body of the Geminids meteor shower. While most of the parent bodies of meteor showers are comets, cometary activity of Phaethon has only been reported near its perihelion at 0.14 AU. Phaethon is likely a comet to asteroid transitional body. Na depletion is reported from visible spectroscopic study of the ground observation of the Geminids meteoroid. Since an expected temperature by solar heating at 0.14 AU is not high enough to sublimate Na from Na-bearing phases, the observed Na depletion is likely derived from surface materials of the parent Phaethon. Na depletion does not occur in chondritic materials, but does occur in differentiated chondrites, such as primitive achondrites, which are subject to melting and segregation of Na-rich silicate melts. Phaethon may hold a signature of comet-asteroid transition body and primitive-differentiated material. Because of its small perihelion distance, dehydration of the surface material by solar heating is expected, but some primitive, hydrous material may still reside in its interior. Phaethon is an ideal body to understand on-going thermal evolution of primitive bodies in the solar system. Further, Phaethon is among the largest potentially hazardous asteroids (PHAs), of which cross the Earth's orbit. Thus, Phaethon is a critical mission target both in the context of science and planetary defense. Here, we present a flyby mission to Phaethon and its related asteroids by the DESTINY+mother ship and its daugther probe "PROCYON-mini", with their scientific significance.

Keywords: Asteroid (3200) Phaethon, Meteor Showers, Meteor shower parent bodies, Primitive bodies, DESTINY+, PROCYON-mini

Size Dependence of Dust Distribution around the Earth Orbit

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In our solar system, there are many interplanetary dust particles (IDPs) originating mainly from asteroid collisions and activity of comets. These particles gradually decrease its angular momentum and drift radially due to the absorption and re-radiation of the sunlight (Poynting-Robertson effect; e.g. Burns et al. 1979). Investigating the properties of the zodiacal dust particles may reveal the properties of parent bodies and the creation process of them.
We analyzed the thermal emission from the IDPs called as the zodiacal light observed via all sky survey by the first Japanese infrared astronomical satellite, AKARI. We found that the observed surface brightness in the trailing direction of the Earth orbit is greater than that in the leading direction by 3.7% in band at 9um and 3.0% in band at 18um. This result is consistent with previous observations with IRAS (Dermott et al. 1994). This asymmetry is thought to come from the asymmetric dust distribution made by the IDPs trapped by MMRs of Earth orbit.
In order to reveal dust properties resulting in the asymmetry of dust distribution, we numerically integrated dust orbits in the Solar system including radiation from the Sun. The orbital evolution can be characterized by the parameter βwhich represents the strength of the radiation force compared to the gravitational force from the Sun. The parameter βcan be defined as a function of dust properties such as dust radius s and material density ρ. In our calculations, particles are set to be 0.001-0.1 in β(corresponding to 3-300um in radius with ρ= 2g/cc) and their initial orbits are determined according to the origins of main-belt asteroids, Jupiter-family comets and Encke-type comets.
We found that larger particles are easier to be trapped by MMRs and make high density region in the dust distribution. However, larger particles are easier to be trapped by outer resonances which hardly contribute to the asymmetry in the surface brightness. In consequence, asteroidal grains of radius 30um are most likely to make the asymmetry in the surface brightness. For cometary grains, due to the high eccentricity, particles are difficult to be trapped by resonance and less likely to make the asymmetry compared to the asteroidal grains.
In this presentation, we show the results of analysis of AKARI observations and orbital calculations and discuss the origin and typical size of the IDPs.

Keywords: Interplanetary dust particles, Earth

Dynamical evolution of dust particles: from comets to the inner solar system

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There have been a long-standing debate regarding origins of interplanetary dust particles. Recent research about the optical properties and spatial distribution of zodiacal light suggested that ~ 90% of interplanetary dust particles which comprise the zodiacal light would be originated from comets. In this work, we started from different point of view. We studied the final status of dust cloud made by the dust particles ejected from comets. We chose representative comets which cover a wide variety of cometary orbital distribution. Hypothetical dust particles with different sizes were ejected from selected actual comets, following a dust ejection model based on cometary observations. We performed a numerical integration of dust orbits involving photon drag from solar radiation and perturbations from planetary gravitation. In this presentation, we will introduce our results about final positions of the cometary dust particles, and compare it with the observed quantities of interplanetary dust particles in the inner solar system, that is, the mass budget, size-frequency distribution, orbital elements distribution and zodiacal light brightness distribution.

Keywords: interplanetary dust particles, comets, zodiacal cloud, numerical simulation

The MMX mission

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Martian Moons eXplorer (MMX) is the mission studied intensively by JAXA with the planned launch in 2022. It will explore the two moons of Mars, namely, Phobos and Deimos, and return samples from Phobos. The sampling will be done after detailed inspection of the moon from quasi-orbits around it is performed, while less detailed remote-sensing is planned for Deimos. The main objective of MMX is to understand the origin of the two Martian moons that remains controversial, with its goal being to reveal how small bodies at the outer-edge of the rocky-planet region behaved upon formation of the solar system. Mars is located at the outer-edge of the rocky-planet region, or at the gateway position to the snow line that demarcates the inner- and the outer-solar system. It is from beyond the snow line that water and volatiles were transported to the rocky planets. Without the across-the-snow-line transport, habitability is not an option for a rocky planet that was born dry inside the snow line. Small bodies, like those we find as primordial asteroids today, must have been the capsule for the transport, and thus, understanding the behavior of small bodies around the snow line during the formation of the solar system is one of the goals of planetary science as well as of MMX. In this talk, the mission scenario of MMX will be introduced and also discussed is the science strategy towards the mission goal via achieving its objectives.

Observation of Mars in MMX mission

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To understand the water cycle and reservoir stability on Mars, investigation of localized water vapor transport and the diurnal cycle of phase change are important. Information obtained so far is quite limited because previous observations from polar, low-altitude orbiters did not obtain snapshots of high-resolution water vapor distribution and did not observe formation/evaporation of localized clouds. To understand dust lifting and the formation of global-scale dust distribution, investigation of fast, localized dust storms is important. Previous observations did not detect temporal development such events.
Observations of the Martian atmosphere in MMX from a high orbit will achieve a breakthrough via continuous, high-resolution global monitoring of dust, clouds, water vapor, and minor gases. The candidate instruments are mapping spectrometers in near-IR and UV, visible camera, and thermal IR camera. The expected outcomes are: spatial distribution of water vapor at fine scales; how water vapor emerges at specific locations, flows over long distances, and forms clouds; location, local time, and timescale of localized dust lifting; and how the lifted dust clouds spread and become diffuse.

Keywords: Mars, Atmosphere, MMX

Key observations to understand the internal structure of Phobos

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Observations of Phobos by many spacecraft such as Viking orbiter, Mars Global Surveyor, mars Odyssey, Mars Express, and Mars Reconnaissance Orbiter provided variety of datasets of the satellite including visible and color images, UV spectrum, global and high-resolution near IR and IR reflectance spectrum, radar reflectance, and precise orbiting parameters. However, because all of these missions have studied Phobos at distance, critical observations such as high-resolution imaging and precise gravity measurements have not been performed yet. In addition, Phobos exists in a very unique circum-Martian environment, which is significantly different from asteroids in the main belt. For example, impacts to Phobos should show the leading and trailing asymmetry due its synchronous rotation, which should also affect the deposition rates of re-impact of ejecta originated from Phobos itself. Also, the surface should have experienced space weathering due not limited to solar wind but also escape irons from Mars. Secondary impacts from Mars may contaminate the regolith of Phobos as well. Thus, understanding these processes is necessary to obtain a basic picture of surface evolution of the satellite. Important and necessary observations in the future mission would include (1) comprehensive mapping of craters and boulders, (2) study of sedimentary structures (if any) of regolith (layers) at high-resolution images, (3) high-resolution observations of geological features including grooves and depressions, (4) understanding of the degree of space weathering and its spatial distribution, and (5) a detection of dust ring on Phobos orbit.
The two distinctive color units observed on Phobos are interpreted in several ways, including an exposure of fresh internal materials over relatively weathered and totally different geological unit. In either case, their nature and understanding the surface processes would be important to derive information regarding its internal structure. Importantly, we do not know if an internal core exist or not, or even if the internal Ice exist (can vary from 0 to 60%). Also, the estimated bulk porosity can vary up to 70% and the surface materials may not represent the body. Therefore, key observations regarding the internal structure would include: (1) Detection of internal water-ice, which may be constrained by measurements of ion flux from inside, (2) Rough structure of the body in terms of gravity, (3) Shallow but precise subsurface structures including regolith thickness, contamination, layering, and the existence of base rock, which may be constrained by gradiometer observation, radar sounder, and lander’s in-situ packages for porosity and particle size, (4) Exact density value at anywhere, which may be performed by Muography instrument.

Keywords: Phobos, internal structure, MMX

The velocity and mass distributions of impact ejecta in the vicinity of the impact point: An application to the material transport from Mars to Phobos

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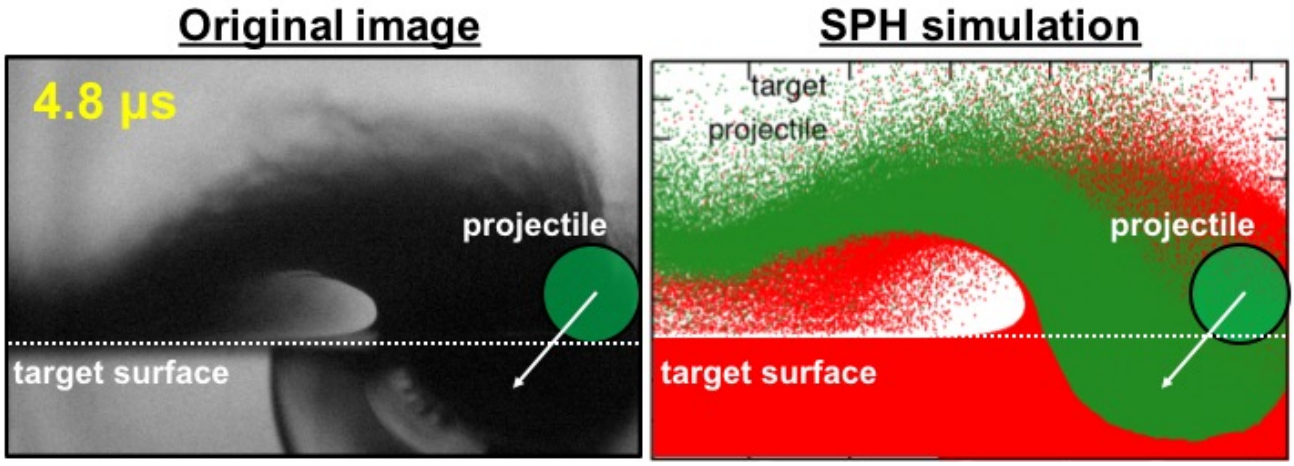
High-speed ejecta produced by a hypervelocity impact are transported to extremely far from the impact point. The surface of a satellite, Phobos, would contain Martian materials ejected by hypervelocity impacts (Ramsley and Head 2013). For understanding how much the ejecta can be transferred to Phobos, it is necessary to investigate the maximum velocity of impact ejecta and their mass in the vicinity of the impact point.
Although previous studies have been studied about the velocity distribution of impact ejecta from the position beyond the impactor's radius (e.g. Hermalyn and Schultz 2011, Tsujido et al., 2015), high-speed ejecta from just below the impact point have not been observed well. The ejection behavior has been also investigated using a numerical code in detail (Johnson et al., 2014). The simulation results, however, have not been validated through a comparison with the results of hypervelocity impact experiments.
In this study, we performed impact experiments in order to observe the high-speed ejecta and to investigate the ejection velocity very near from the impact point using ultra-high-speed video camera. While the ejection velocity can be measured from the obtained images, it is difficult to determine the mass of the ejecta from impact experiments. We also performed SPH simulations of the impact ejecta in order to compare with the experimentally-observed ejection behavior under the same impact conditions, and to confirm the validity of the simulations. We investigated mass distribution of both target and projectile components in the ejected material in the simulations.
We used polycarbonate as both projectiles and targets. Impact experiments were conducted using two-stage light gas guns at PERC/Chitech and ISAS/JAXA, Japan. Impact velocities were 3.56-7.04 km s^{-1}. Impact angles were 90 degrees and 45 degrees measured from the target surface. High-speed video cameras (Shimadzu, HPV-X1, HPV-X2) were used, and the frame rate was 0.2 μs $frame^{-1}$, which enables us to observe the high-speed ejecta in the vicinity of the impact point because this time was much shorter than the time for a projectile penetration. The two cameras were used at ISAS/JAXA to observe the impact ejecta from two different directions in a right angle. This allows to reproduce three-dimensional images during impact processes.
Impact simulations were carried out with a three-dimensional SPH code (e.g. Genda 2012). The Tillotson EOS for polycarbonate was adopted (Sugita and Schultz 2003). We used 10^4, 10^5, and 10^6 SPH particles for a projectile to investigate the effects of the spatial resolution on the ejection behavior.
High-speed images show that a pattern of the ejecta curtain in the vertical impacts was almost axial symmetry like an umbrella. On the other hand, it was asymmetry in the oblique impacts, and two components of ejecta in different traveling directions were observed. One moved along the target surface to the downrange of the projectile trajectory. This is considered to be produced due to a jetting process during a projectile penetration (Kurosawa et al., 2015). The other component expands to the upward of the target surface. The boundary of the two component was observed as a kink. We confirmed that the SPH code with the highest spatial resolution, i.e., 10^6 SPH particles, reproduces the ejection behavior, including the travel distance of the outer edge of impact ejecta

and the two component in oblique impacts. The edge of the ejecta curtain consists of the target material during a vertical impact, whereas the leading edge of the ejected materials along the target surface is dominated by the projectile material during an oblique impact. We will discuss the application of the results to the problems of a material transport from Mars to Phobos.

Keywords: ejecta, hyper-velocity impact experiment, SPH simulation



Origin and evolution of Phobos: Scientific objectives awaiting particle measurements by MMX

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In this presentation, we will present scientific objectives of particle measurements by the Mars Moon eXploration (MMX) mission. The MINE (Magnetic field, Ion and Neutral Experiment) package consisting of five instruments (MSA, MIA, REN, NIMES, and MGF) and MEC (Mars Escaping atmosphere Capturing device) have been proposed as possible payloads of the MMX mission. MINE and MEC would perform particle measurements corresponding to the following three scientific objectives: (1) To obtain indirect information on the Phobos internal structure in order to constrain the origin of Phobos independent of the sample analysis results. (2) To characterize the space environment and the surface features of Phobos, with the intention of comparison with asteroids. (3) To constrain the total amount of atmosphere lost from Mars to space during its history. Details of these three scientific objectives will be presented.

Keywords: Phobos, Mars, Particle

Gamma-ray and Neutron Emission from the Surface of Martian Moons

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Mars has two moons "Phobos" and "Deimos" which have never been explored. Japanese mission to Martian moons "Mars Moon eXploration (MMX)" is planned to obtain some evidences for determining the origin of Martian moons. This mission will pick up rock and soil sample from Phobos to the Earth to analyze in detail by laboratory techniques. There are two influential scenarios about the origin of the Martian moons, captured asteroid origin and giant impact origin. However, any previous studies have never succeed to explain the origin of the Martian moons completely.
The chemical composition of the Martian moons which is essential information for planetary science has not been observed before. Gamma-ray and Neutron Spectrometer (GNS) is proposed as one of the mission payloads in order to determine elemental compositions of two Martian moons by remote sensing. The captured asteroid origin indicates Martian moons of primitive chondritic composition which enriches with volatile elements (H, S) and depleted with Si and Ca [1]. On the other hand, Martian materials ejected by the giant impact made the moon if they have similar composition to Mars which is considered to be rich in Si and Ca [2]. Moreover, volatile elements are depleted because of evaporation by impact heat. Therefore, the ratios of Si/Fe, Ca/Fe and H concentration will be important indicators to give a constraint to the origin of Martian moons.
In this work, we have investigated gamma-ray and neutron emission depending on chemical composition and H concentration to support the potential to distinguish sample compositions by the GNS. The elemental composition of Martian meteorites and some types of chondrites were assumed as the giant impact origin and the captured asteroid origin, respectively. H concentration in these elemental compositions were varied in the range of 0-20000 ppm. Production and transportation of gamma-rays and neutrons produced by galactic cosmic rays (H and He; 10 MeV/n-100 GeV/n) were calculated by using the Monte Carlo simulation code PHITS (Particle and Heavy Ion Transport code System) [3] and the INCL (Intra Nuclear Cascade of Liége) nuclear interaction model [4].
The Si/Fe and Ca/Fe ratios of gamma-rays emitted from Martian composition showed high values while that from chondrite composition showed low values. There are some differences in the shape of neutron energy spectra between Martian and chondritic samples. The neutron energy spectrum from chondrite shows a peak at the energy range of thermal neutron < 0.5 eV and a low flux of epithermal neutron energy from 0.5 eV to 500 keV comparing to that from Martian meteorite. In contrast, the shapes of fast neutron flux > 500 keV almost correspond. It is considered that the differences of H concentration in the sample composition caused this differences in neutron spectra since H atoms moderate neutrons effectively. The neutron fluxes were significantly varied depending on H concentration. Fast and epithermal neutron fluxes decreased with H concentration while thermal neutron flux increased until 2000 ppm of H and decreased above the value. Epithermal neutron flux is effective to determine H concentration since the change of epithermal neutron was larger than that of thermal and fast neutrons. By combining the ratios of Si/Fe and Ca/Fe and H concentration determined by gamma-rays and neutrons, the GNS will give an important constraint to the origin of the Martian moons.
The simulation results of the Martian moons will be presented and discussed.
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Keywords: Gamma-ray and Neutron Spectrometer, Martian moons, GNS

On the origin of Martian moons

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We will review the origin of Martian moons with our recnet works. We will also present the science aspects of the MMX mission.

Keywords: sample return, Martian moons, origin

