ISAS Planetary Exploration Workshop 2024

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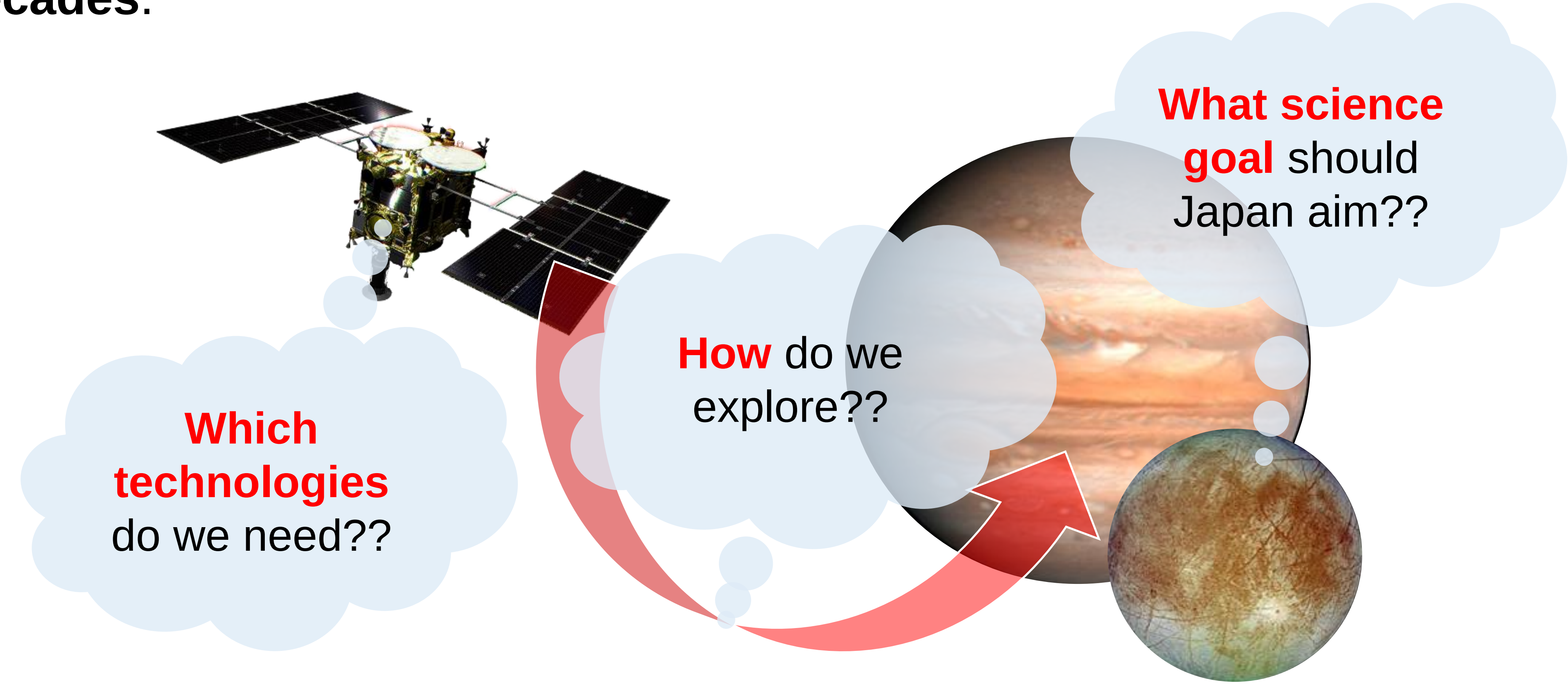
Naoya Ozaki, Go Murakami & SOC members

2024 Sep 2-4

Motivation

This workshop is to present the latest research results from **both science and engineering that will lead to future new mission proposals over the next few decades**.



Interaction between ISAS PEWS and Tohoku SPS

<Summer>
Scientist x Engineer
- Backgrounds
- Science requirements
- Technical challenges/approaches

<Winter>
Scientist (mainly)
- Backgrounds
- Science goals
- Science requirements

Mission
seeds/concepts
Study team

Science goals
Science requirements

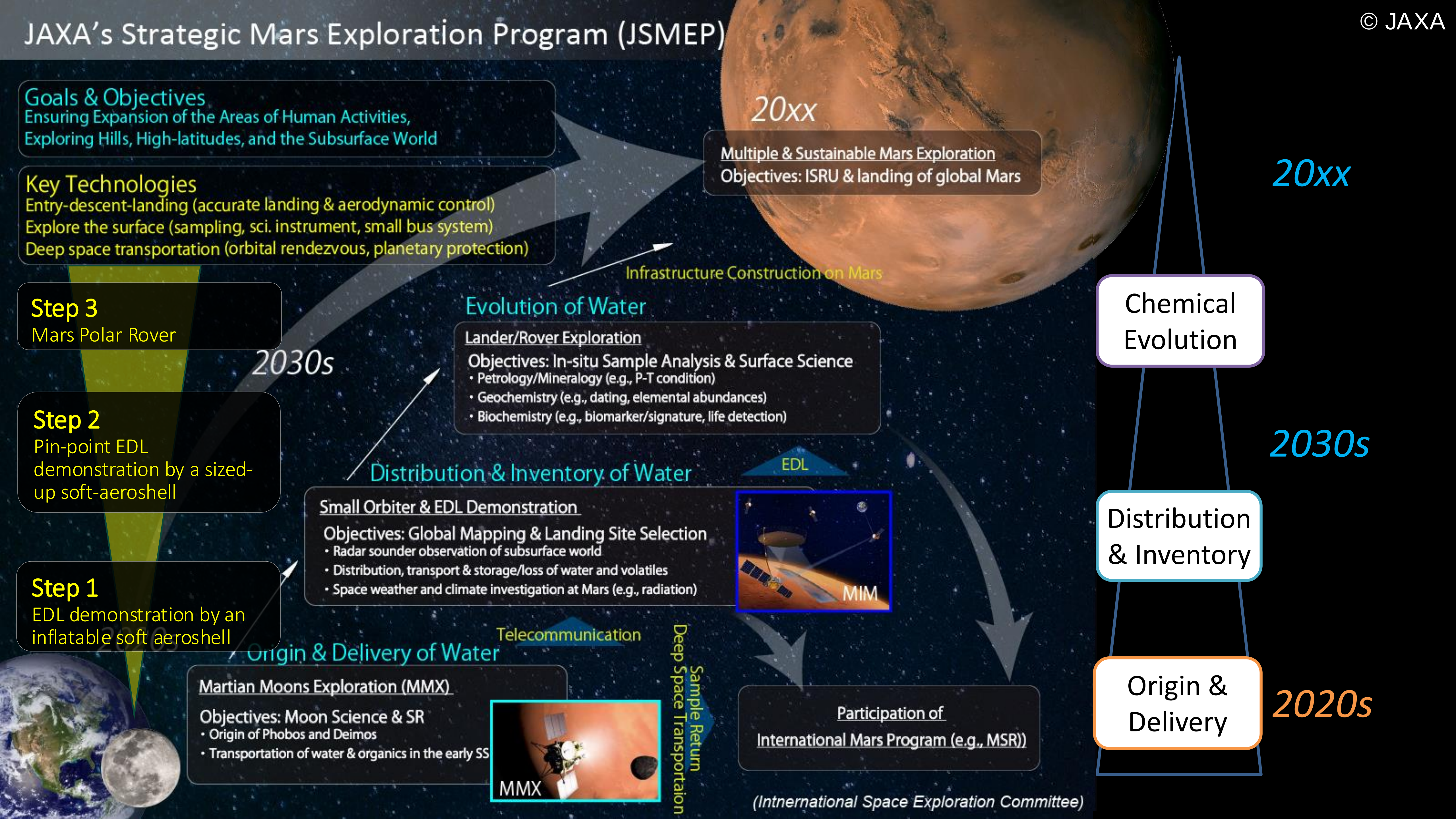
X-NIHONBASHI TOWER, Tokyo, 4 September 2024

ISAS Planetary Exploration WS 2024
~ Mars Splinter ~

- **Splinter contents: Step 1 landing site and I-MIM science if time permits**
  1. **Landing site for Step 1**
  2. **Science with I-MIM**

Splinter-lead members:

Shotaro Sakai, Rina Noguchi, Shunta Kimura, Mizuho Koike, Kei Masunaga, Arihiro Kamada, Yasunori Nagata, & Tomo Usui


JAXA's Strategic Mars Exploration Program (JSMEP)
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Goals & Objectives
Ensuring Expansion of the Areas of Human Activities,
Exploring Hills, High-latitudes, and the Subsurface World
Key Technologies
Entry-descent-landing (accurate landing & aerodynamic control)
Explore the surface (sampling, sci. instrument, small bus system)
Deep space transportation (orbital rendezvous, planetary protection)
20xx
Multiple & Sustainable Mars Exploration
Objectives: ISRU & landing of global Mars
Infrastructure Construction on Mars
Step 3
Mars Polar Rover
2030s
Evolution of Water
Lander/Rover Exploration
Objectives: In-situ Sample Analysis & Surface Science
• Petrology/Mineralogy (e.g., P-T condition)
• Geochemistry (e.g., dating, elemental abundances)
• Biochemistry (e.g., biomarker/signature, life detection)
Step 2
Pin-point EDL
demonstration by a sized-up soft-aeroshell
Distribution & Inventory of Water
EDL
Small Orbiter & EDL Demonstration
Objectives: Global Mapping & Landing Site Selection
• Radar sounder observation of subsurface world
• Distribution, transport & storage/loss of water and volatiles
• Space weather and climate investigation at Mars (e.g., radiation)
MIM
Step 1
EDL demonstration by an
inflatable soft aeroshell
Telecommunication
Origin & Delivery of Water
Martian Moons Exploration (MMX)
Objectives: Moon Science & SR
• Origin of Phobos and Deimos
• Transportation of water & organics in the early SS
MMX
Deep Space Transportaion
Sample Return
Participation of
International Mars Program (e.g., MSR))
(Intnernational Space Exploration Committee)
20xx
Chemical Evolution
2030s
Distribution & Inventory
2020s
Origin & Delivery

Overview of stepwize Mars landing program (From Yamada-san)

The stepwise Mars program will be closely related to lunar and deep-space exploration missions.

<Lunar Exploration>

From 2020s

SLIM,
LEAD,
LUPEX….

・Thruster
・Landing system with retro-jet.

・Rover

<Mars landing Program>

Front Loading (~2020s)
Development of OTV and inflatable aeroshell.

Step 1 (~2030)
Demonstrate orbital transfer by OTV and safe landing by inflatable aeroshell.

Step 2 (~2035) (e.g., I-MIM)
Enhancement of aeroshell function. Demonstrate pinpoint landing and soft landing with retro-jet.

Step 3 (~2040)
Size up of aeroshell.
Mars rover for science mission.

<Deep-space exploration>

・Common OTV

2030s ~

- Sample return mission from deep space.
- Flyby exploration to deep space with small satellite.
- Others…

What did we discuss in the splinter after 2020?

What are the science interests?

- **Atmosphere-cryosphere-lithosphere interaction**: Upper-lower atmospheric coupling, atmosphere-surface-subsurface interaction, Phobos-Mars interaction, Volatile and water inventory, photochemistry and aerosols, outgassing-volcanic history, interior history, oxidation-reduction history
- **Atmosphere-space interaction**: Role of intrinsic magnetic field for habitability, Space weather (SEP, UV, SW), Chemical evolution, Impact on prebiotic molecules
- **Life and organic geochemistry**: Origin of organics-preservation, Subsurface/surface difference, Life and water detection, Life evolution
- **Subsurface science**: Paleo (and current?) habitable environment, Lava tube, Polar ice, Internal structure

Methodology, Observations, and Measurements to achieve?

- Seismic observation, Geological measurement, Magnetic field measurement, Radiation (energetic particle) measurement, Bio-signature and prebiotic molecule detection, Isotope ratios, Space-weather package, and Weather package.

Where to go?

- Volcano, Polar region, Crustal magnetic field in the southern hemisphere, Lava flow channel, etc.

Splinter discussion

In the past, splinter sessions have had only a limited and short discussion time, often forcing the session to end in the middle of a discussion. At this time, we have a total session time of 4.5 hours.

Topics on which we want to focus in this splinter

Focus on Step 1 landing site and I-MIM science if time permits

1. Landing site for Step 1
   - Scientific priority of two scenarios
   - Candidates of realistic landing site based on required landing accuracy, etc. w/ engineers
   - Science at the landing site and matching science instruments and collaboration with other missions
   - Planetary protection
   - Scientific possibilities with OTV
2. Science with I-MIM
   - Sharing the progress of the scientific/instrument study with EDL after SPS
   - Science with orbiter

From Sekine-san's slide

Step 1: Science Concept

- How long did Mars have a dynamo-induced magnetic field?
- How much is water contained in mantle? Any 3-D structure in mantle?
- How extensive is groundwater? Global or local?
- Any ongoing hydrothermal activity near active magmatism site?

Is Mars alive? To determine the activity, supply, & loss of water

【Potential Scenarios】

Scenario 1 (hot scenario): Current activity of water at volcanic region	**[Elysium Mons & Plan.]** How extensive is groundwater present in northern lowlands? Are there hydrothermal activities today? Is there mantle plumes and how much water is contained? In Scenario 1, landers will investigate groundwater extents, volcanic, and hydrothermal activities. The amount of water in the mantle beneath volcanoes (evolved mantle?) is also measured.
Scenario 2 (cool scenario): Extent of groundwater & water in mantle	**[Southern highlands]** Groundwater may be present at InSight's landing site (lowlands), but is it global? How about southern highlands? How long did Mars have a magnetic field? In Scenario 2, the presence of deep-crustal groundwater in southern highlands is investigated. Also, remnant magnetic fields and water contents in the mantle of the southern hemisphere (primitive mantle?) are measured.

A few-sentence summary from invited talks

Taichi Kawamura: What We Learned from InSight and Our Next Steps for Martian Seismology

- Crust 20-40km, thick mantle (500km, thermal lithosphere) + fully molten silicate layer (BSL) , liquid iron core with 17 wt% S.
- Marsquakes are active in southeast of Elysium, but not enough data for other regions (e.g. Tharsis)
- Water in mid crust?
- Sheer velocity jump at ~1000 km depth, depending on the model (mineral composition)
- Molten layer on core?

Yasuhito Sekine: Science Targets for Multiple Landers on Mars

- To understand Mars as a system from the core to magnetosphere.
- Super volatile rich core H, S, O, C 10-15 wt% (InSight lander)
- Ground water in liquid? in 10-20 km depth at InSight landing site.
- Step1 : to understand exchange of materials between the interior and surface
- Potential scenario: Hot scenario (current activity of water at volcanic region) (landing to Elysium Mons & Plan.) & cool scenario (Extent of groundwater & water in mantle) (Southern highlands)
- potential science payload: magnetometer, seismometer, weather package (with wet chemistry), camera / spectrometer
- Wet chemistry: silicon chip device for GC or LC
- + small Robotics (<1 kg) as a sub-payload such as LEV-2 for SLIM

A few-sentence summary from invited talks

Masahiko Sato: Magnetic Field Investigation on the Martian Surface: A Case for the Crustal Remanence

- Internal structure, history of dynamo, and space weather by B field obs.
- Remanence of crater
- Dynamo history: Evaluate interior dynamics and surface environment.
- TARGET in Step1: Verification of the dynamic cessation after about 4 Gyrs ago, variation in magnetic field during the dynamo period, changes in magnetic field during the dynamo cessation, and optimization with targets of magnetic sounding & space weather monitoring

Naoki Terada: Search for Underground Water on Mars with Magnetic Field Measurements

- Electrical resistivity (conductivity) sensitive to water layer in shallow depth and water content in mantle //ionospheric currents
- Prove electrical conductivity with external perturbations (26 day solar rotation, diurnal ionospheric currents), Measure B as a sum of induced, external and ionospheric fields -> extract induced
- Ex and nabla B_H?
- Potential method for conductivity investigation: HSG method or Spherical harmonics analysis
- HSG method needs station distance shorter than wavelength (~100s km) in the ionosphere.

A few-sentence summary from invited talks

<u>**Yohey Suzuki**: Analog Rock Studies for the Detection of Life on Mars</u>

- PP for backward contamination from Mars with SSAP group
- Microbial lifes are detected from basalt rock (drilled from terrestrial ocean)
- Mineralogy (basaltic base rock, smectite from water-rock interaction) is similar to most Mars rocks
- Potential target for subsampling is pore-rich or clay-rich rocks
- Non destructing analysis with FT-IR, FT-IR Microscopy and O-PTIR
- O-PTIR can detect one single cell. Test with analog rock is ongoing.
- Bioburden control (< 50 spores / m^2)

<u>**Ken Goto**: Overview of Small Mars Lander in Step 1</u>

- 3 or 4 micro landers inserted from Mars orbit. Probe Mass 20 kg per lander. Size 350 mm in diameter x 750 mm
- Micro lander with inflatable aeroshell, 3 m in diameter, penetrates to Mars surface. Impact speed 50 m/s. attack angle ~ 20 degrees. Survive time ~ several months.
- Landers can communicate to orbiter.
- Science payload ~ 1.5 kg.
- Electric power supplied by thin film solar cells on aft membrane aeroshell. several 100 W.
- After landing, it is warmed at night by heater and battery. low temperature rechargeable battery.
- Planetary protection system in ISAS/JAXA will be established for STEP 1. Bioburden room space 4 m x 3.5 m.
- Science instruments: Seismometer, such as LUNAR-A and Dragonfly.

A few-sentence summary from invited talks

Kanako Seki: Overview of Step 2 (International Mars Ice Mapper)

- Reconnaissance mission for future human exploration to Mars
- Mapping of subsurface water and ice by the synthetic aperture radar (SAR)
- Mars orbiter in circular orbit, with EDL Demonstration.
- Three science objectives by MDT: Geosphere, Habitability, Atmoephere
- Expectation of JAXA contribution: Sub-mm sounder, UV-VIS camera (atmomspheric package) for element 1 (orbiter), Demo lander and its science payloads for element 2 (demo lander)

Splinter discussion

1. Discussion on landers

- Need for multiple landers:
  - It is necessary to consider the merits and demerits of scenarios in which no more than three landers are required, and scenarios in which even one lander can succeed.
- Science Payload:
  - Install the same observation instruments on multiple landers.
  - If more than three observations are required, four or more units are desirable for redundancy.
    - The issue is whether OTV can carry it.
- Constraints on lander weight:
  - Whether all of the science payloads currently under consideration can be carried in Step 1 depends on the weight.
- Landing accuracy and penetration depth:
  - When targeting high-latitude areas, landing accuracy and penetration depth should be considered.
  - There are concerns about contamination of underground ice, which is an important issue from a planetary protection perspective.

Splinter discussion

2. Discussion on landing sites

- Multiple-point observations:
  - Observations at multiple points are essential to detect the presence of water and hydrothermal fluids in the mantle and crust.
  - Observations of crustal remnant magnetic fields are not a problem at a single point.
- Observations in high latitude:
  - It is possible that in the future, special regions in high latitude regions may be targeted, but they may not be targeted in Step 1.
- Observations at the north-south hemisphere boundary:
  - The subsurface structure of the boundary region between the northern and southern hemispheres is still poorly understood, and probing the interior structure of Mars with seismic waves is of great scientific value.
  - If one point of observation is in the northern hemisphere and the other in the southern hemisphere, it would lead to great science (as well as understanding the Martian subsurface structure).
  - In terms of Mars magnetic field observation, three points within 100 km is not a problem for understanding the history of the Martian magnetic field, but a significant change in the geological structure of several subsurface layers for observing the subsurface water distribution is not very desirable.
- Observations in the Southern Highlands:
  - The Southern Highlands are valuable because of the different types of seismic waves that can be observed with InSight.
  - It would also be valuable if the layered mid-crustal structure captured in the underground at InSight could be observed in the Southern Highlands.
  - Because Valley Networks and other zones have been observed in the Southern Highlands, it is possible that traces of water may still be present.
- Observations in areas with strong crustal remanent magnetic fields:
  - Because crustal magnetic fields are strong even below 45° latitude, such locations can be targeted.
- Observations by soft landing for Step 2:
  - If a soft landing is possible, in-situ analysis can be accomplished.
  - Landing site candidates are locations where the presence of water is suggested to be about 1 m below ground level, or in polar regions.
  - Since the subsurface structure can be estimated in conjunction with the short-period seismometer, a long-period seismometer should be placed in Step 2 or later, if a soft landing is feasible.

Splinter discussion

3. Discussion on the value of observation data

- Weather model validation:
  - Observations at new landing sites are important because adding new observation points that are different from past explorations will help validate existing models.
- Understanding dust storms:
  - Targeting the degenerating edge of the CO_2 polar cap (about 45 degrees latitude) may advance our understanding of the mechanism of dust storms that expand from that area.

4. Discussion on technical issues

- EDL weight limit:
  - The weight of the EDL is limited to 30 kg if it is to utilize the heritage of the observation rocket to date.
  - OTVs can also carry observation equipment, but allocating payload there may reduce the amount of payload that can be sent to the EDL.
- EDL timing:
  - After confirming the first successful EDL landing, the next aircraft is dropped.
  - The time difference is expected to be about one week, depending on the OTV.
- Dispersion area at landing:
  - The lander's fall dispersion area is expected to be 150 km in the long axis direction and 50 km in the short axis direction, which is wider than the lunar surface.
- Power supply and temperature control:
  - For earthquake observation, it is more important to know the position after the fall and how long it takes to observe multiple points simultaneously than the accuracy of the fall position. If time difference < lifetime, there is no problem.
  - Battery degradation in low-temperature environments constrains their lifespan, and heaters are needed at night (when there is no sunlight) due to the low-temperature environment. Temperature control of observation equipment is an issue, and heater power is tight, making it difficult to further warm up observation equipment.
  - From Step 2 and beyond, the landing will be a soft landing in a reverse thrust configuration, so unlike Step 1, which is a penetration configuration, the soil cannot be used to retain heat. Since it will be necessary to heat propellant such as hydrazine, there is no prospect of being able to afford heater power, even for Step 2.

Splinter discussion

- Hardness and softness of the ground at the landing site:
  - The penetrator is designed for trampled soil. If it is too soft, it may dive, and if it hits lava or other rocks, it may bounce back and fall over.
  - Need to consider how likely it is to hit rocks.
  - Crater edges may be too soft.
  - InSight selected a site with a sand layer of about 5 – 10 m as the selection site.
- Challenges of multiple-point observations
  - To observe the subsurface water distribution with a magnetometer, three points need to be placed within a few hundred kilometers of each other. Since there is a conflict with other sciences, it may be possible to substitute one point by placing a magnetometer on the orbiter side as well.
  - It is not desirable to have three points within a few hundred kilometers of each other to significantly change the geological structure of the subsurface.

5. From Step 1 to 2

- The interval is assumed to be relatively short (about 10 years).
- The same type of aeroshell is used for Step 1 and Step 2 (soft landing).
- The engineering study for Step 2 is underway at the same time.
- The overall weight of Step 2 is expected to be about 150-200 kg.

Step 1 Science Matrix	URL: https://docs.google.com/spreadsheets/d/1YghbiSRZjARf_kuEHqzLJbTpBPPLzAM7yKQvn_vKMvo/edit?gid=1197910431#gid=1197910431						
Science target	Scenario	Methods	Landing sites	Minimum # of landers	If # of landers increases...	Remarks	References, etc.
Water and hydrothermal fluids in the crust	Hot	Magnetometer/Seismometer	Elysium Mons & Plain (Active volcano region)	3		Within several hundred km. It is less desirable for the geologic structure to change significantly.	
Water and hydrothermal fluids in the mantle	Hot	Magnetometer/Seismometer	Elysium Mons & Plain (Active volcano region)	3		Within several hundred km. It is less desirable for the geologic structure to change significantly.	
Crustal magnetic field obeservations	Hot/Cold	Magnetometer	Southern Highland? (Strong magnetic field region)	1	Increasing the observation points leads to a detailed understanding of the present and ancient Mars magnetic field system.	Possible in strong locations below 45 degrees latitude.	
Underground structure	Hot/Cold	Seismometer	Martian dichotomy & Southern Highlainds	2		If one point of observation is in the Northern Hemisphere and the other in the Southern Hemisphere, it leads to great science.	
Recent past hydrothermal system (habitable world?) in possible active volcaninic field	Hot/Cold	Visible camera? In-situ analysis (how?)	Central Elysium Planitia (rootless cone fields)	1	If # > 1, plenty of data is expected based on surveys in several RC fields.	Exploration of the shallow subsurface world on Mars accessing through rootless cones. Dense rootless cone fields would be better.	Exploration of the shallow subsurface world on Mars accessing through rootless cones
Subsurface ice	Cold	In-situ analysis (how?)	Northern mid-high latitude & northern pole	1		Requires the soft landing for Step 2.	
Weather model validation	Cold	Weather package	Sites with no observations so far	1			
Polar cap activity	Cold	Weather package	Polar cap	1			
Dust storm mechanism	Cold	Weather package	Northern middle latitude	1			

Summary & Homework

Summary

- There are merits and demerits for landing sites in both hot and cool scenarios.
- We need to be worried about the number of landers because we need to take four landers including the redundancy if we want to make observations by three landers.
- We need ongoing discussions.

Homework

- Create the “list of won-and-lost records” of one lander and three landers in each of the hot and cool scenarios based on the splinter discussion.
  - We will try to make it by the end of September.

Moon session splinter meeting

SOC: 長岡央, 西野真木, 仲内悠祐, 小野寺圭祐

- 今回の講演のフォローアップ
- 討論：SLIMで獲得したピンポイント着陸技術＋その観測運用経験を次世代の月惑星探査にどう活用できるのか
- 月面サンプルリターンへの応用
- 月面サンプル分析、月面環境計測の将来計画

今回の講演のフォローアップ

	Name	Title	Keywords
Invite1	Takayuki Ishida (JAXA/ISAS)	Smart Lander for Investigating Moon (SLIM): How we achieved pinpoint landing	SLIM, Engineering
Invite2	Yusuke Nakauchi (Ritsumeikan Univ.)	MBC onboard SLIM: New Functions and Operational Reality in the era of the Lunar Landing Exploration	SLIM, Science observation
Invite3	Hiroshi Nagaoka (Ritsumeikan Univ.)	Science aimed at through sample return from the Moon and sample analysis strategy	Sample return
Invite4	Satoshi Kurita (Kyoto Univ.)	Plasma and electrostatic environments surrounding the Moon and their exploration	Plasma

Ishida

- ✓ landing Shioli crater, with landing site selection by using LRO data (0.9 m/pixel) and Chadrayaan-2 data (0.27m/pixel)→事前の危機回避のため
- ✓ Vision-based Navigation search landing site with the crater positions
  →画像照合による着陸地点を探す
- ✓ 高度@50mでの推定精度は3～4m、(最終的には~60m離れたところに着陸 support by LROC)
- ✓ 越夜は３度成功

<u>将来探査への適用について</u>

- ✓ Difficult to detect enough landmarks at lunar polar
- ✓ 火星でできるのか？（仲内）→Mars2020ではできている、大気次第
- ✓ 火星ではどれぐらいの精度が必要か？（仲内）→100mくらいSLIMと同程度（関根）
- ✓ 画像イメージの差は、月は白黒の土壌、火星は赤い土壌？（長岡）
  モノクロを使うのでその点は問題ない。ランドマークの特定が困難な為、火星地形を新たに定義
  月の極域で難しいのは日照高度の問題（ランドマークの特定が困難になる）、５度６度までは覚悟

Nakauchi

- ✓ マントルカンラン石の探索
- ✓ その場観測運用ではリアルタイムで予期せぬ事象が起こりうるのでLesson&Learnを詰みかさせねていくことが重要（他の探査との情報共有を）
- ✓ ミラーの稼働、Auto focusを月面で実証した、これは今後のカメラでも必要な機構
- ✓ Two types of rocks were identified mafic-poor and mafic-rich with combined 10 band images.
- ✓ スラスターの吹上の影響はあるのか？（三宅）
  →スラスターが吹いた領域から少し離れた場所での観測、レゴリスも乗ってない
- ✓ 越夜の違いによりダスト観測に影響があったか？（三宅）
  →越夜の違いを検証できるデータは取得できていない（仲内）

Nagaoka

- ✓ JAXA FS/FLの枠組みでサンプルリターンミッション枠組みを検討してきた。
- ✓ 衝突溶融岩、始原的な地殻岩をターゲットして太陽系衝突史の復元、LMOとジャイアントインパクト仮説の検証
- ✓ これまでのSRとの大きな違い
  →新鮮な路頭から放出された数m規模の岩塊からサンプルを持ち帰ることが鍵
- ✓ リモセン観測との整合性を確認するためその場分析でのサンプル分析が重要
- ✓ その場分析装置の開発とサンプル分析を比較できる統合的な枠組みを構築中
- ✓ 元々想定されていたLEADミッションよりも、早く帰ってくるであろうアルテミスのサンプルに関してもここの枠組みを利用して議論を進めておく（長岡、深井）

Kurita

- ✓ 月周辺の環境、Feasibility of exploring of plasma environment around the Moon
- ✓ Lunar Surface Charging: Global View caused by the interaction between plasma and lunar surface
- ✓ Charging of dust grains on the lunar surface
  → 有人探査でもここらの知識は重要。赤道域と極域で変わり得るのか？
- ✓ Surface charging : scale dependence?
  →Global Scale（周回）, topography scale（縦穴）, microscale（レゴリス）
- ✓ Development of portable radiation & plasma detector
- ✓ The roadmap for search on the surface charging
  → Gateway and Cubesat firstly
- ✓ 月百葉箱(どれくらいの大きさ)、どのようにして運ぶ（機会？）
  →lander, OTVの機会、多点観測
  →バスを作らないといけない（仲内）、バスをどう作るか？JAXAと議論（栗田）
  →インターフェイスを共通化したい
- ✓ 月震のバス、通信も共通化していきたい（川村）
- ✓ 多点観測、どのような場所におきたいか（川村）
  →月の環境もにたーなのでばら撒いて起きたい（栗田）
- ✓ 宇宙飛行士が置くことを想定？orOTV（木村）
  →あんまこだわりのない、こちらの出した要求を満たしてくれれば

次世代の月探査にどう活用できるか？

ピンポイント着陸技術

- 極域もしくは月高地の裏側へのピンポイント着陸の困難さ
  →極域は日照高度が課題となる
- 参照する画像イメージの明度や色彩の影響は？
  →インパクトメルト領域へ暗い領域
  →画像処理の観点からは平らな海の方がやりやすい
  →裏側に降りることに関しては中継機器を利用するのが現実的である
  →中継衛星を利用して情報を収集する
  →月と火星の色彩の違い：影響はないだろう

装置を月面にどう設置するか

- ハードランディング or not, 月面設置精度を装置ごとに整理
- 各装置のインタフェースの紹介や整理調整をこのような場を活用して今後議論できたら良い

SLIM Landing技術 to Mars

- 火星での着陸を想定した場合（木村）

→姿勢ブレの補正ができれば原理的にできるのでは?（石田）

→エアロシェル後にカメラ画像取得？誘導には画像航法

Planetary Exploration WS splinter: small bodies

3rd, September, 2024

Session lead:
Naoya Sakatani, Ryota Fukai, Tetsuya Kusumoto,
Shota Kikuchi, Eri Tatsumi,

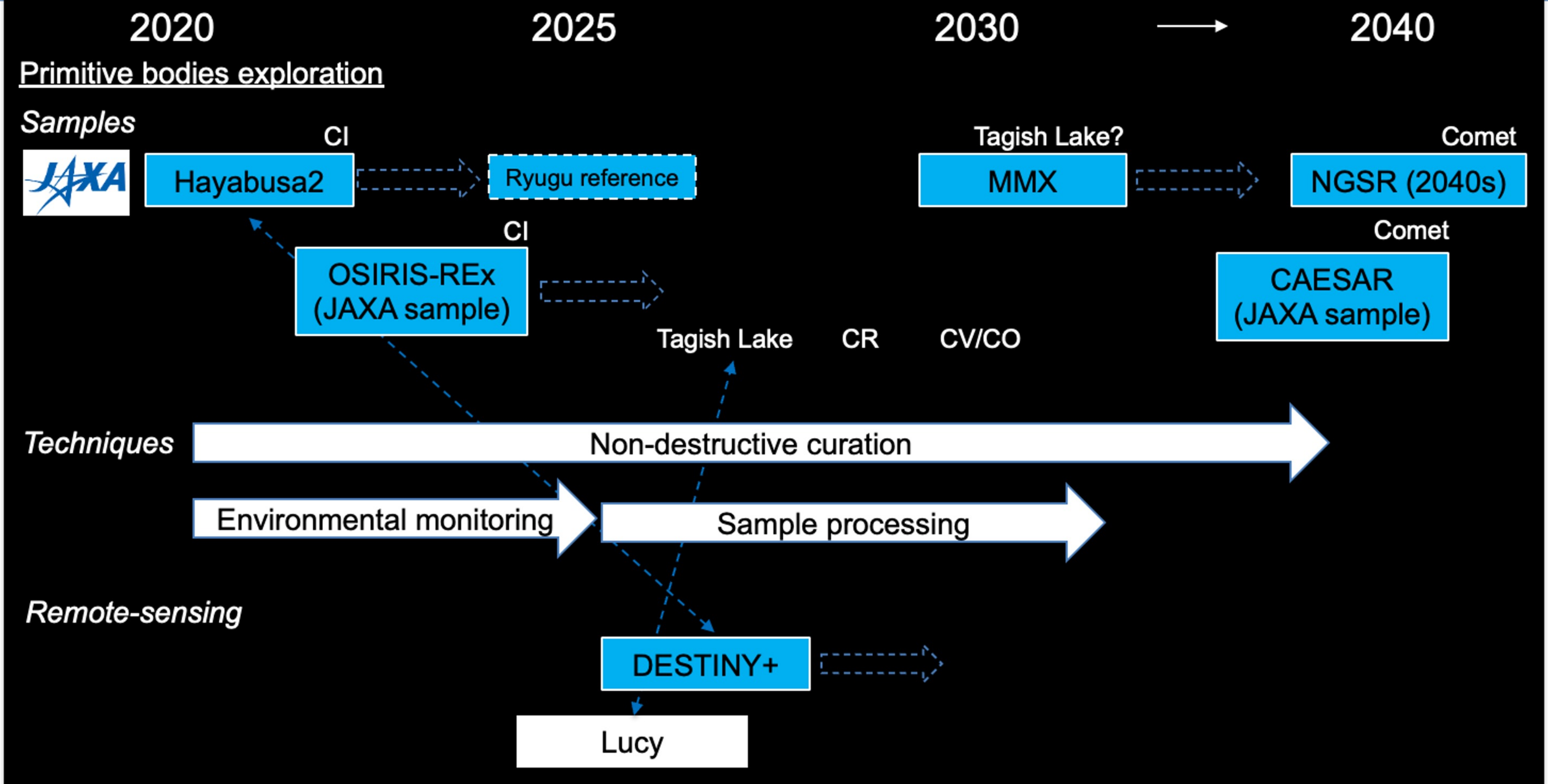
Topics

- L-class
  - MMX (2026–2031), NGSR (2030s–2040s)
- M-class
  - DESTINY+ (2025–), new mission (flyby and/or smallsat)?
- International
  - Hera, Comet Interceptor

Output from this splinter (Fukai et al. (2023) Yuseijin (in Japanese))

	Science goals	Potential targets	(1) Science: Key information	(2) Engineering: Key techniques	(3) Exploration methods	Analogs
planetary science	**Delivery of volatiles to the Earth**	C-type asteroids	chemical composition (organics, volatiles) isotopic composition (organics, volatiles)	terran-relative navigation	sample return (Hayabusa2, O-REx) rendezvous (-) flyby (DESTINY+)	Carbonaceous chondrites (biased)
		Comets	chemical composition (organics, volatiles) **isotopic composition (organics, volatiles)**	cryogenic SRC outer exploration	sample return (Stardust, CAESAR) rendezvous (Rosetta, NGSR) **flyby (Comet Interceptor)**	IDPs (biased)
	Formation of planetary bodies	*(goal: Jupiter, Trojans)* Trojan asteroids	isotopic composition (organics) mineralogy	outer exploration	sample return (-) rendezvous (-) flyby (Lucy)	-
		(goal: terrestrial planets) E-type asteroids	isotopic composition (refractories) chemical composition (refractories)	-	sample return (-) *meteoritics (enstatite chondrites)*	Enstatite chondrites
		(goal: planetesimals) Comets, D-type asteroids	**mechanical properties, global shape** isotopic composition	outer exploration	sample return (NGSR, MMX) **rendezvous (Rosetta)** flyby (Comet Interceptor)	IDPs (biased, small-scale)
	Evolution of planetary bodies	*(goal: differentiation of planetesimals)* M-type asteroids	chronology magnetic property	-	sample return (-) rendezvous (Psyche) *meteoritics (iron meteorites)*	Iron meteorites
biology	**Evolution of biomolecules**	C/P/D type asteroids	chemical composition (organics) isotopic composition (organics)	cryogenic SRC outer exploration	sample return (Hayabusa2, O-REx, MMX) rendezvous (Rosetta)	Carbonaceous chondrites (possibly biased) IDPs (biased, small scale)
astronomy	**Origin of Solar System**	Comets	chemical composition (refractories) isotopic composition (refractories)	outer exploration	sample return (NGSR)	IDPs (biased, small-scale)
disaster prevention science	**Planetary defense**	NEA (<100 m)	mechanical property non-gravitational effects	terran-relative navigation super small body exploration 尾崎ほか議論の内容	rendezvous (Hayabusa2#, Hera, O-REx) flyby (Hayabusa2#, DART) *ground-based observation*	

Vision: Solar System eXploration (Curation)



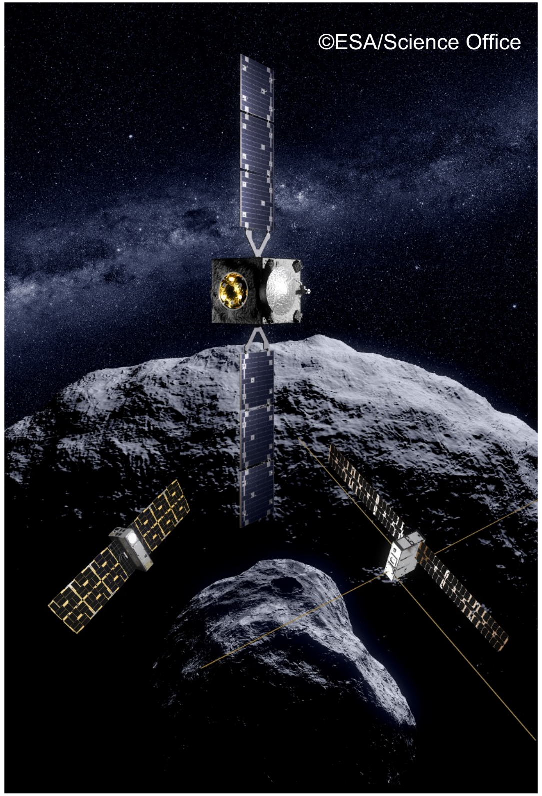
Recent update/Today's talk (science)

- Space Telescopes
  - Gaia DR3: visible spectra of >60,000 solar system objects
  - JWST: new era for NIR-MIR spectroscopy!
    - High wavelength resolution, High sensitivity
    - **TNO, primitive asteroids (Mario's talk)**
      - **There are more distinct reservoirs than we thought…? (CO2 snowline, ammonia snowline, etc.)**
      - **Transition between TNOs, Centaurs, asteroids, and comets.**
  - Upcoming…
    - SPHEREx (2025 Launch): NIR
    - Twinkle (2025 Launch): VIS-NIR
    - Roman Space Telescope (2027 Launch): VIS-NIR
    - ARIEL (2029 Launch): VIS-NIR
    - LAPYUTA (early 2030s): FUV
    - NUV wavelength is missing…

Recent update/Today’s talk (science)

- Planetary Defense misisons
  - Hayabusa2# to 1998KY26
  - OSIRIS-APEx to Apophis
  - Hera to Didymos after DART impact
    - *Launch on this October!*
  - RAMSES to Apophis

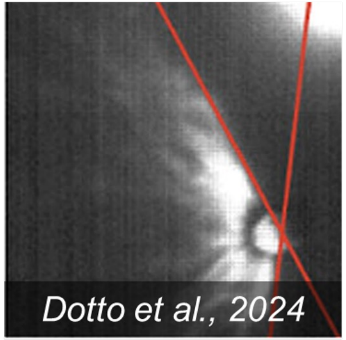
- Next Generation Sample Return (NGSR) mission
  - Comet sample return mission
  - First proposal was submitted on July (be not the selection at this moment).
  - Final proposal will be submitted in 2027.



Recent updates / Today’s talk (Engineering)

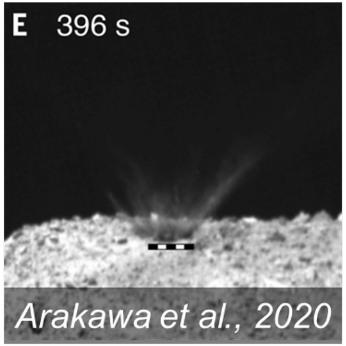
- When pursuing low-cost missions, they would take the forms of either **flyby** and/or **smallsat** missions (though not limited to these options).
- Past/Ongoing missions
  - DART-LICIACube, HERA
    - Flyby ejecta plume observations
  - Lucy (Dinkinesh flyby)
    - High-resolution imaging (2.2 m/px)
  - Hayabusa2-DCAM3
    - Optical-only orbit and att. determination
- Future missions
  - Hayabusa2# (2001 CC21 flyby)
  - NGSR
  - DESTINY+
  - Deep space constellation

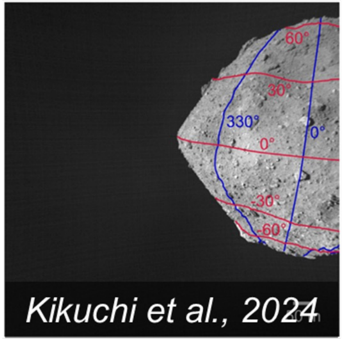
LICIACube
(14 kg, 7 km/s)



Lucy
(1.5 ton, 4.5 km/s)

DCAM3
(0.58 kg, <1 m/s)





Science Today's talk

- Space Telescopes
  - Gaia DR3: visible spectra of >60,000 solar system objects
  - JWST: new era for NIR-MIR spectroscopy!
    - High wavelength resolution, High sensitivity
    - **TNO, primitive asteroids (Mario's talk)**
      - **There are more distinct reservoirs than we thought…? (CO_2 snowline, ammonia snowline, etc.)**
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    - ARIEL (2029 Launch): VIS-NIR
    - LAPYUTA (early 2030s): FUV
    - NUV wavelength is missing…

Summary

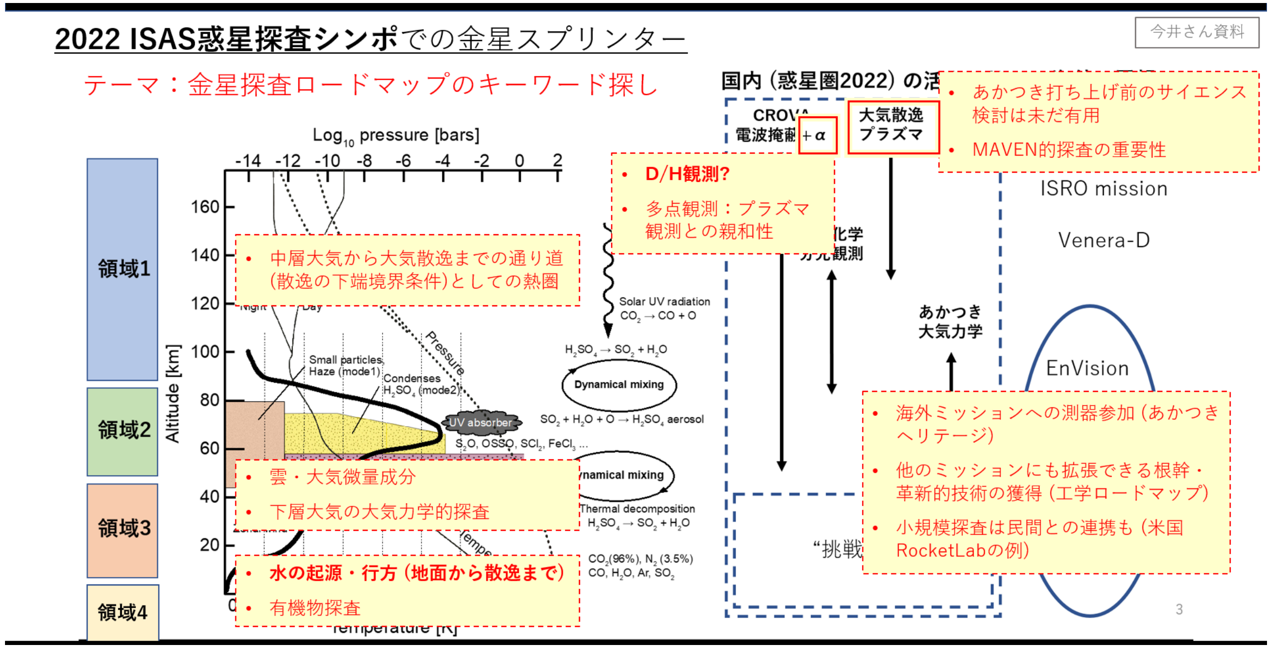
- Even though space telescopes provide rich scientific data, direct exploration is essential for determining the physical parameters of small bodies, such as thermophysical characteristics and densities/porosities.
- By leveraging recent flyby and smallsat technologies (e.g., Hayabusa2#, DESTINY+, DART-LICIACube, Lucy), even M-class missions can accomplish advanced tasks.
- Rendezvous and even sample return could be achieved with cutting-edge technologies, such as solar electric propulsion for the outer Solar System and solid-motor sampling probes for massive targets.
- Higher fuel costs limit payload capacity and observation data, making it crucial to select a mission type that aligns with scientific objectives.

ISAS PEWS 2024 - Venus splinter

Splinter leads: H. Sagawa, Y. Kawabata, M. Imai, T. Kouyama,
K. Odagiri, H. Ando, Y. Harada, G. Murakami

Discussions on the past Venus splinter

- 2022 **Venus Exploration Research Group** in JAXA/ISAS
- 2022 ISAS/PEWS Creating a Science Road-Map for future Venus explorations
- 2023 ISAS/PEWS Strategy for proposing a new mission (Step-1) in 2030's.



(A) New mission in 2030's (targeting JAXA's Small-class mission)

Potential ideas: **How much resources is acceptable for the science payloads?**

・If launched with H3 (so, it's not 公募型小型 though), 2,500 kg for total spacecraft.

(1) **CROVA**：Cross-Link Radio Occultations to fully map the temperature field.

(2) **CROVA** + ***α*** (other instruments on mother-ship).

(3) **Orbiter mission**：MAVEN for Venus. / **Long-term (climate) monitoring?**

・What kind of physical parameters to be monitored?

・Period, Cadence? - one Solar cycle?

(4) **CubeSats from Earth orbit?**

・Point-source like image is still informative.

(B) Further-future mission with developing new technologies

Surface exploration, Deep lower atmosphere, In-situ measurements of clouds, Sample-Return mission, etc. *Seeds for the Next generation planetary explorations*

Interplanetary transfer using kick-motor + lunar gravity assist

Cross-link radio occultation between two satellites ・Application to other planetary atmospheres.

- **2024 ISAS/PEWS** Focusing on "**CROVA**" mission concept

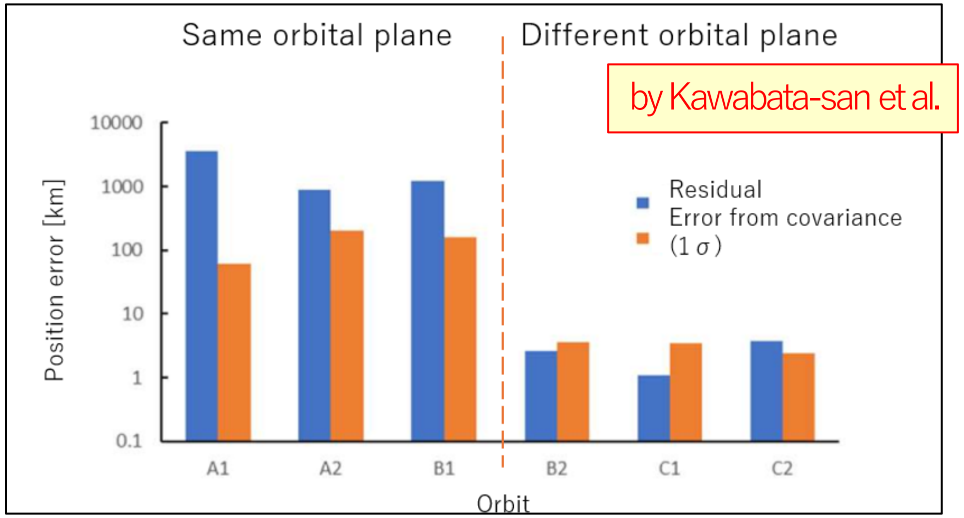
Three invited talks

- **Dr. Takeshi Imamura** (U. Tokyo) *Exploration of planetary atmospheres with satellite-to-satellite radio occultation missions*
  - Radio occultation technique for Venus = Unique & powerful tool to study inside the thick cloud layer and above. Ionosphere can also be sounded. CROVA (satellite-to-satellite cross-link radio occultation) = 1 chief sat. & 2 deputy sat. increase the measurement sampling density drastically. Also improve the data assimilation quality.
  - Can be applied to other planetary atmospheres, such as Mars. For Mars, only the day/night terminator is observable from the ground, but with sat-to-sat system full global mapping can be achieved. Surface pressure map can be obtained.
  - ESA's M-class M-Matisse will employ sat-to-sat radio occultations but with L-band which is less sensitive to the lower atmosphere.
- **Mr. Michinari Kake** (U. Tokyo) *Mission design for Mars atmospheric observation using inter-satellite radio occultation*
  - Detailed mission design of a sat.-to-sat. radio occultations for Mars atmosphere. 1 chief sat. & 1 deputy sat. can fit with a small sat. concept. In terms of mass, power, etc., a practically feasible result is obtained.
  - Orbit is optimized by examining the number of the measurement points and the delta-V cost. The chief sat. carries a Hall thruster for orbit control. Achievable accuracy for the orbit determination is currently under study.
  - Mission data downlink to the ground is also examined.
- **Dr. Norihiko Sugimoto** (Keio U.) et al. *Observing system simulation experiment (OSSE) for the cross-link radio occultation measurements of the Venus atmosphere (CROVA)*
  - Numerical models for Venus atmosphere (AFES-Venus) and its data assimilation system (ALEDAS-V) are producing successful results recently. Satellite measurements as *eyes*, and GCMs as *brain* to understand the planetary atmospheres.
  - First challenge of data assimilation to Venus atmosphere. Data assimilation studies can improve the model parameters in GCMs and also quantitatively evaluate the scientific performance of new mission measurements (OSSE).
  - OSSE is quite straightforward approach to optimize the mission design. Scientific significance of the CROVA's multiple sat.-to-sat. radio occultations are demonstrated.

Summary of Venus splinter 2024

- **Orbit Determination Accuracy** for daughter (deputy) satellites (cannot communicate directly w/Earth)

  - OD via radio communication between chief sat. and deputy sat. → Putting all satellites into the same orbital plane has an advantage in reducing delta-V, but cannot achieve sufficient good OD accuracy.
  - From scienctific requirement, **ODA of ~1 km** is needed. → Putting at least 1 sat. into **a different orbital plane** is needed.
  - Additional **optical observation/navigation approach** is under considered. Use of StarTracker (STT) camera.
  - "OD of deputy sat. via using a chief sat." should be **a common technology** needed for future multiple small satellite explorations.



- Application of radio occultation technique **to other planets.**

  - **Venus or Mars** – which is technically more feasible? → **Thermal condition** is largely different. Currently each of Venus (CROVA) & Mars (Kake-san's talk) are not optimized in terms of ease of implementation.
  - From scientific point of view, **Venus seems more interesting** as uniqueness of measuring inside the cloud.
  - Although challenging, future exploration of **Titan**'s atmosphere is also a possibility.
  - For the data assimilation, **duration of the observation (mission life time)** is also a key factor.

- Connecting CROVA **with other Venus explorations**

  - CROVA provides T(z) = **a fundamental physical parameter in planetary atmosphere**. Can contribute to interpretation of other Venus exploration data set.
  - Mission proposals should not be limited to JAXA's frame work, but should also consider NASA's **SIMPLEx and others**.

Summary of Outer Planets Splinter Discussion in PEWS2024

Leads: Shuya Tan, Shotaro Sakai, Yuki Takao, Yuki Kubo, Ryoichi Koga

Summary of Outer Planets Splinter Discussion in PEWS2024

Goals: Discussion for scientific significance (especially, in terms of SGEPPS)
& possible achievements in case-by-case & depending on targets
for current & future RG for explorations

Summary of Invited Talks

- Dr. Saito
  Small sat as potential hardware serving for International missions
  Less thermal leakage, & simultaneous multi-point observations
- Dr. Sugahara
  MULTUM-Sp (small size high-precision mass spectrometer)
  Precise isotopic analysis for small molecules & organic molecules
- Dr. Takao
  Ion Engine + Solar Array Propulsion for deep space explorations
  Rendez-vous mission to Main belt asteroids, Trojans, Centaurs, Irregular moons

➢ Japan Uniqueness & Strengths

Summary of Outer Planets Splinter Discussion in PEWS2024

Scientific Significance

Variety on each planetary system

- Jupiter System:
  Strong radiation, moon-magnetosphere / moon-to-moon interactions
- Uranus System:
  Helical magnetosphere (difference between rotational and magnetic axes)
  Radiation to moons; Similarity with Saturation System

- What is remained after situation after large international missions? (JUICE, Europa Clipper, Uranus Orbiter & Probe, Enceladus NF)

Summary of Outer Planets Splinter Discussion in PEWS2024

Japan Uniqueness & Strengths, and Capability, What can be achieved?

Key 1: Altitude from targets

e.g., MULTUM: Capable for relatively dense gaseous targets

Electromagnetic observations: Close distance is better for structural analysis

Key 2: Distance from Earth

e.g., Size of solar sail become too large at far distance

Heat tolerance varying for trajectory (repeating hot & cold environments)

Solar power limits ~ Power limits for instruments ~ Measurement ability limits

Key 3: Propulsion system; Feasibility depending on propulsion types (electric or chemical propulsion)

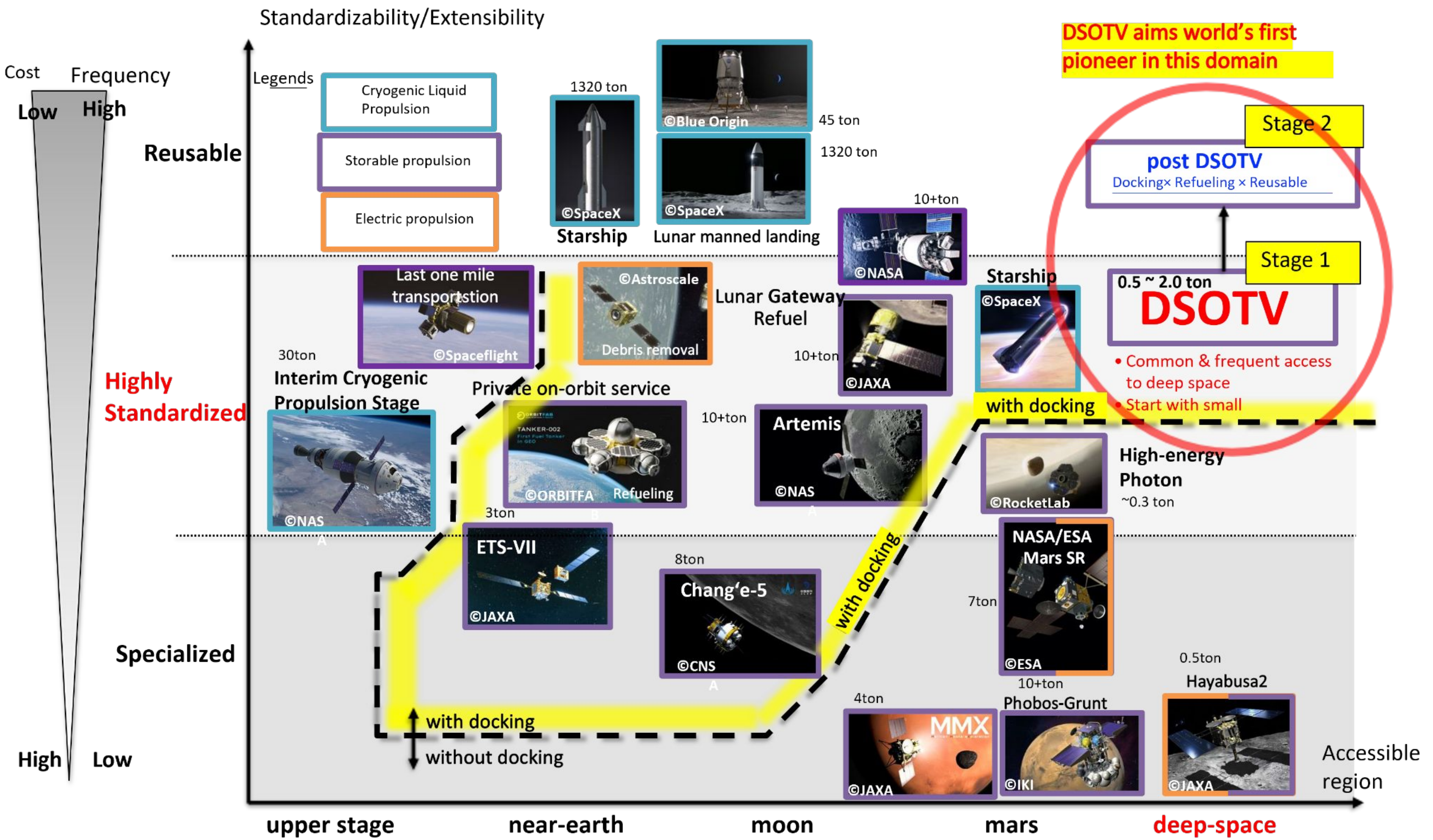
Summary of Outer Planets Splinter Discussion in PEWS2024

Topics toward Next (Future) Discussion

- Traceability matrix for scientific topics in post-large missions
  (JUICE, Clipper, Uranus O&P)
- Upper limit cases of scientific requests
  (Landing? Sample Return?)
- Scientific requests as parameter settings
  (Target, altitude, velocity of flyby, payload)
- Appropriate propulsion systems for requests
  (electric or chemical)

Engineering special session on Deep Space Orbit Transfer Vehicle (DSOTV)

Engineering session SOCs



Q1. What is the NEEDs for OTV? Q2. How do we grow the SEEDs of current OTV?

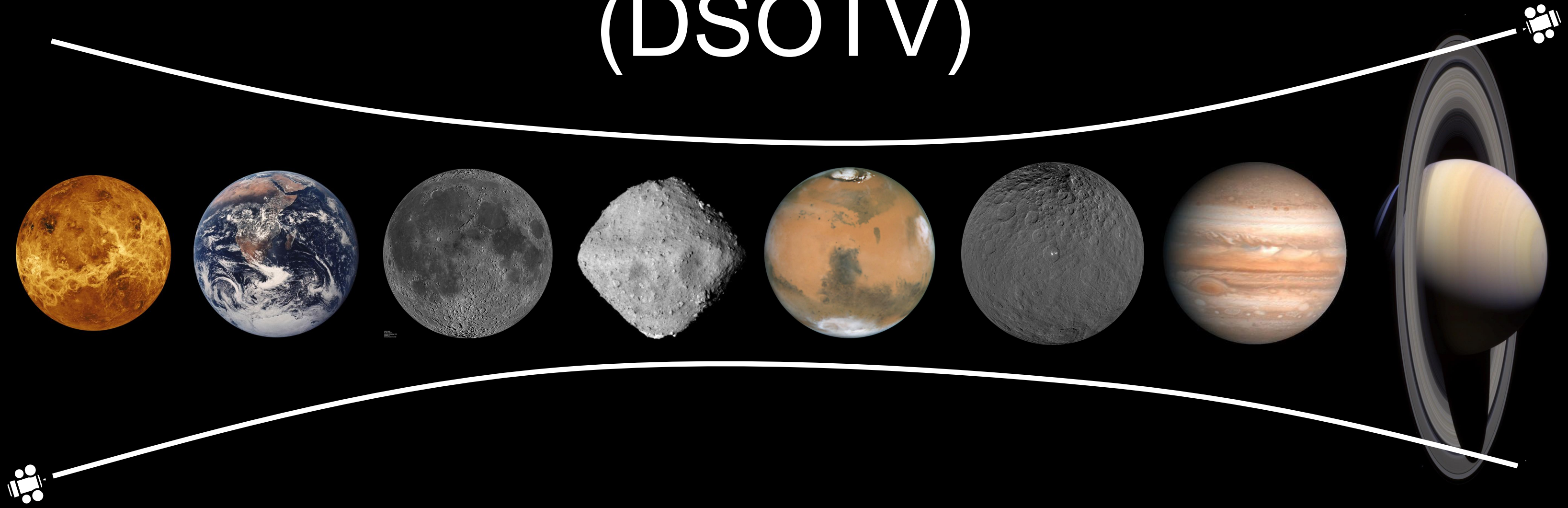
Special session on Deep Space Orbit Transfer Vehicle (DSOTV)

- 9:35-10:35 Invited talks “Introductions to DSOTV”
    - 9:35- Overview of Deep Space Orbit Transfer Vehicle, Yuichi Tsuda
    - 10:09- Transportation Capacity of Deep-Space Orbital Transfer Vehicles, Yuki Takao
- 10:50-11:50 Short talks “Examples of potential applications”
    - 10:52- Small bodies, 11:04-Mars, 11:18 Outer planets, Venus, Saturn
- 11:50-12:00 Introduction to the workshop afternoon

- Lunch break -

- 13:00-14:30 Workshop 1 (On-site only)
    - What value do we aspire to create in future missions, and how can OTV contribute to this?
- 14:45-16:15 Workshop 2 (On-site only)
    - How can we leverage Deep Space OTV in potential future missions?
- 16:30-17:45 Summary of whole workshop, closing remarks (Hybrid)

Workshop on Deep Space Orbital Transfer Vehicle (DSOTV)



Yuto Takei, Yuki Kubo, Yuki Takao, Yusuke Oki

Purpose of this workshop

- OTVの可能性を一緒に考える。
  Think together about the possibilities of OTV.

- 『発散』する機会をつくる。
  Provide opportunities for “divergent thinking”.

- 惑星探査界隈へ『OTV串』を通す。
  Build and strengthen lateral relationship in the planetary exploration community through “OTV”.

Agenda

- ✔ **Discussions are held mainly in Japanese**
- ✔ **Slide written in both English and Japanese**
- ✔ **Discussion in Group A will be held in English.**

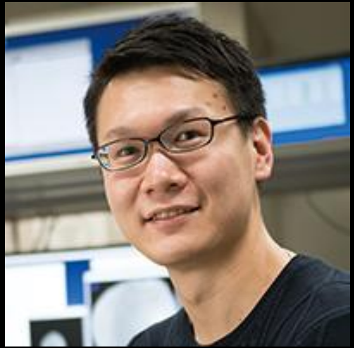
1. Intro + Ice break (15min)
   - ✔ What's your ◯◯◯ "Exploration"?
2. Future Values Workshop (80min)
   - ✔ In future missions, what value do we aspire to create?
   - ✔ How can OTV contribute to them?

~Coffee Break (15min)~

3. Forecast Workshop (80min)
   - ✔ How can we leverage 2t-class DSOTV in future missions?
4. Wrap up (5min)

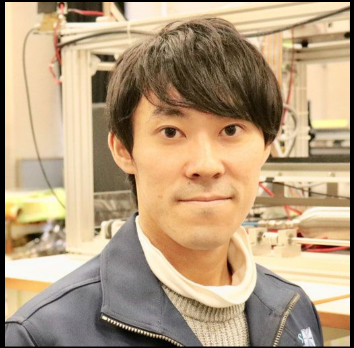
Introduction of Workshop Leads

Yuto Takei



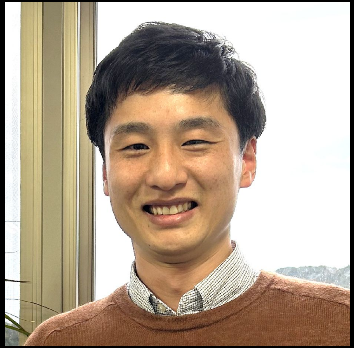
#Hayabusa2
#System
#OTVer

Yuki Kubo



#OPENS
#GNC
#OTVer

Yuki Takao



#NGSR
#System
#OTVer

Yusuke Oki

#MMX
#System
#OTVer

Ground Rules

1. まずは”共感“を。

“Empathy” is the first step.

自分の考えと真逆の意見が出てきたとしても、
相手の立場になって「どういう前提・価値観でこうした意見が出てきたのだろう」
と“共感”的に議論しましょう！

2. 専門外の話題でこそ活躍 しましょう。

Be active even when the topic is outside your area of expertise!

専門外の話題では無言になりがちですが、「聞き手として意見の詳細や背景を引き出す」
重要な役割が残っています。アクティブな聞き手として振る舞いましょう！

3. 誰か一人だけが話すのでなく、 全員同じ量話せるように 。

Make sure that everyone can speak the same amount, not just one person.

お互いが意識して、全員が同じ量話せるように、積極的に問いかけましょう！

What's your ◯◯◯ "Exploration"?

グループ内での自己紹介タイムです。
Time for self-introductions within the group.

1. **持ち時間は各自「1分」目安でお願いします。**
   Each person has 1 minute for self-intro.

2. **初めに「氏名＋所属」を共有して下さい。**
   Please share your "name + affiliation" first.

3. **自分の「◯◯な"探査"」についてシェアして下さい。**
   Please share your ◯◯◯ "Exploration".
   e.g., 好きな探査、最近の探査、失敗した探査
   Favorite exploration, recent exploration, failed exploration

Group Work 1: Value Creation

Future Values Workshop/ Identification

1. OUTCOMES
自分が夢を感じる、将来の惑星探査が生み出す『価値』とは？

2. OUTPUTS
その価値に繋がる『成果物』は？

3. ENABLERS
その成果物の『獲得手段』は？

思いついたことを Post It に書き出してみよう！

Write down what comes to your mind in Post It!

できる限り、たくさん書き出そう！
他メンバーの思いつきに便乗しよう！
Write down as many ideas as you can! Join in on other members' ideas!

※遠慮無用、質も不問、量が正義！
（自分の分野でなくてもオッケー！）

制限時間: 15min

13:35まで

Group Work 2: OTV as ENABLER

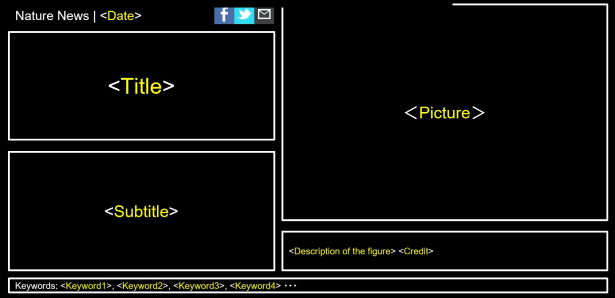
Future Values Workshop/ Conceptuation

① 未来のNature News記事トップをチームで考えよう！
何個でもつくろう！記事の どこかに必ず『OTV』の文字を入れましょう。

Let’s create the Nature News articles of the future!
Be sure to include the word “OTV” somewhere in your article.

② グループで好きなコンセプトを 一つ選び、Google Slidesのフォーマットへ清書しよう。キーワードも忘れずに！（英単語、 5〜7つ）
Choose one of your group's favorite and write it up in Google Slides format.

TEMPLATE



制限時間: ~~35~~ 40min

14:20まで

Planetary Exploration Workshop 2024 Day3（2024/09/04）

Group Work 3: Leverage DSOTV

Forecast Workshop/
Conception

① 『2t-class DSOTV』を使った、CML1-2 のミッションコンセプトを、グループで一つ 設定し、時間の許す限りを深めよう。Google Slidesフォーマット上のテンプレートを埋めよう。

Let's set up one CML1-2 mission concept using "2t-class DSOTV" as a group and deepen it as much as time permits, filling in the template on Google Slides format.

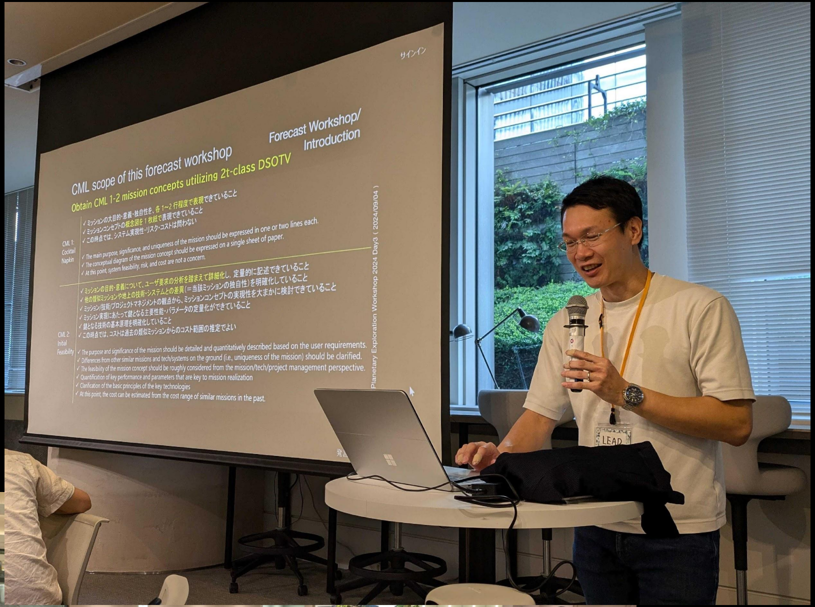
TEMPLATE

天体 Target Body		ミッション名 Mission Name	
ミッション概要 Mission Summary		サービス要求 Service reqs. to DSOTV	

DSOTV構成で実現できること What can be realized from DSOTV config.		DSOTVを用いない実現方法 Mission arch. w/o DSOTV	
DSOTVを活用することの利点 Pros on utilizing DSOTV		DSOTVを活用することの課題 Cons or challenges on utilizing DSOTV	

制限時間: 40min

15:55まで



Planetary Exploration Workshop 2024 Day3 (2024/09/04)