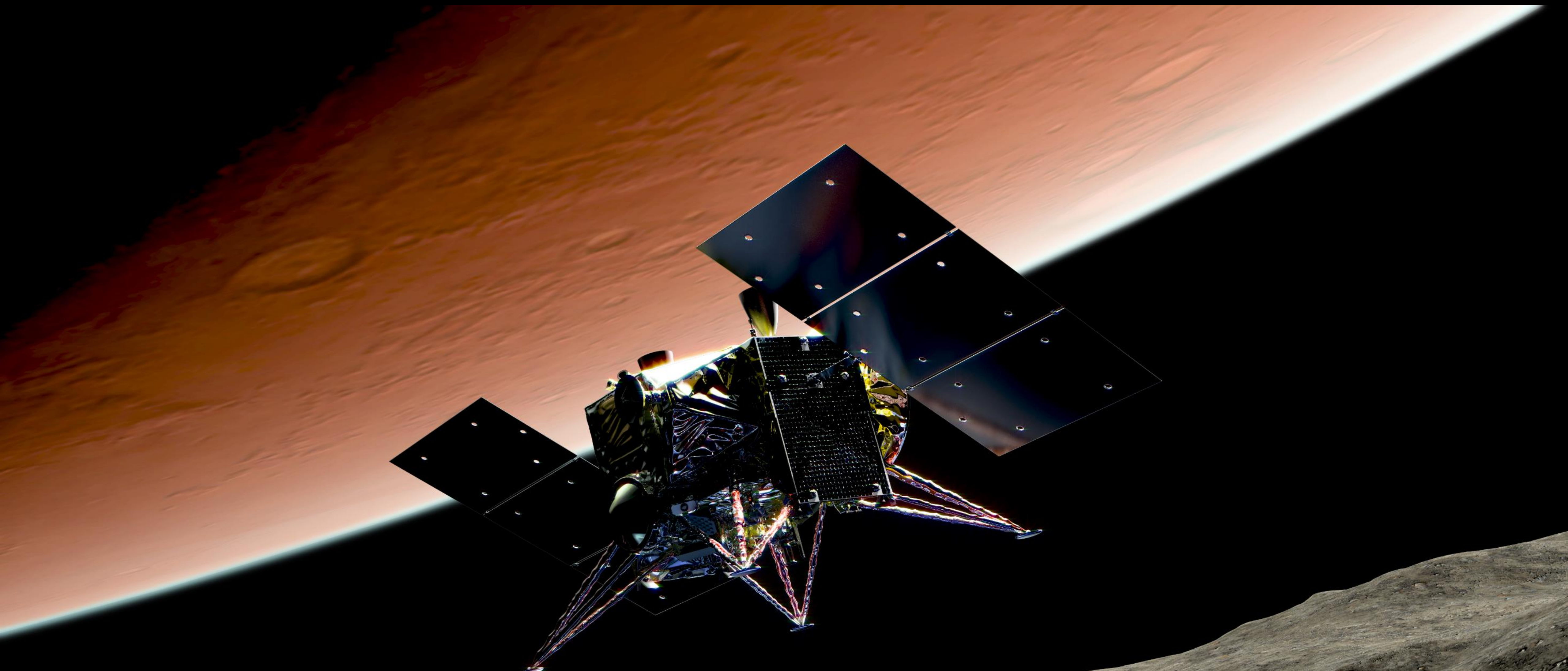
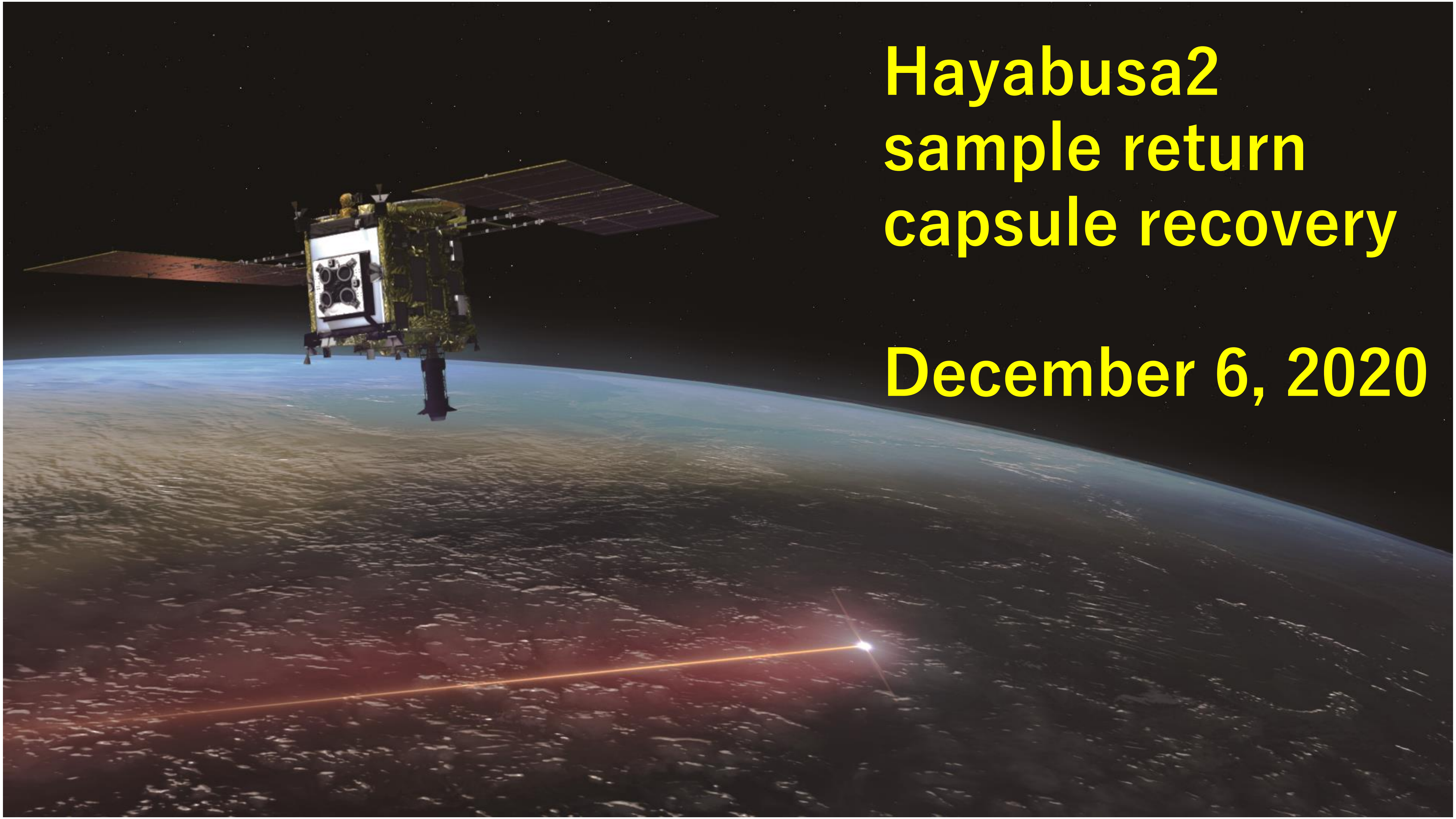


JAXA’s Strategic Mars Exploration Program for Understanding Origin, Evolution, Inventory of Water on Mars

Masaki Fujimoto (JAXA)


Hayabusa2
sample return
capsule recovery
December 6, 2020

Big catch!

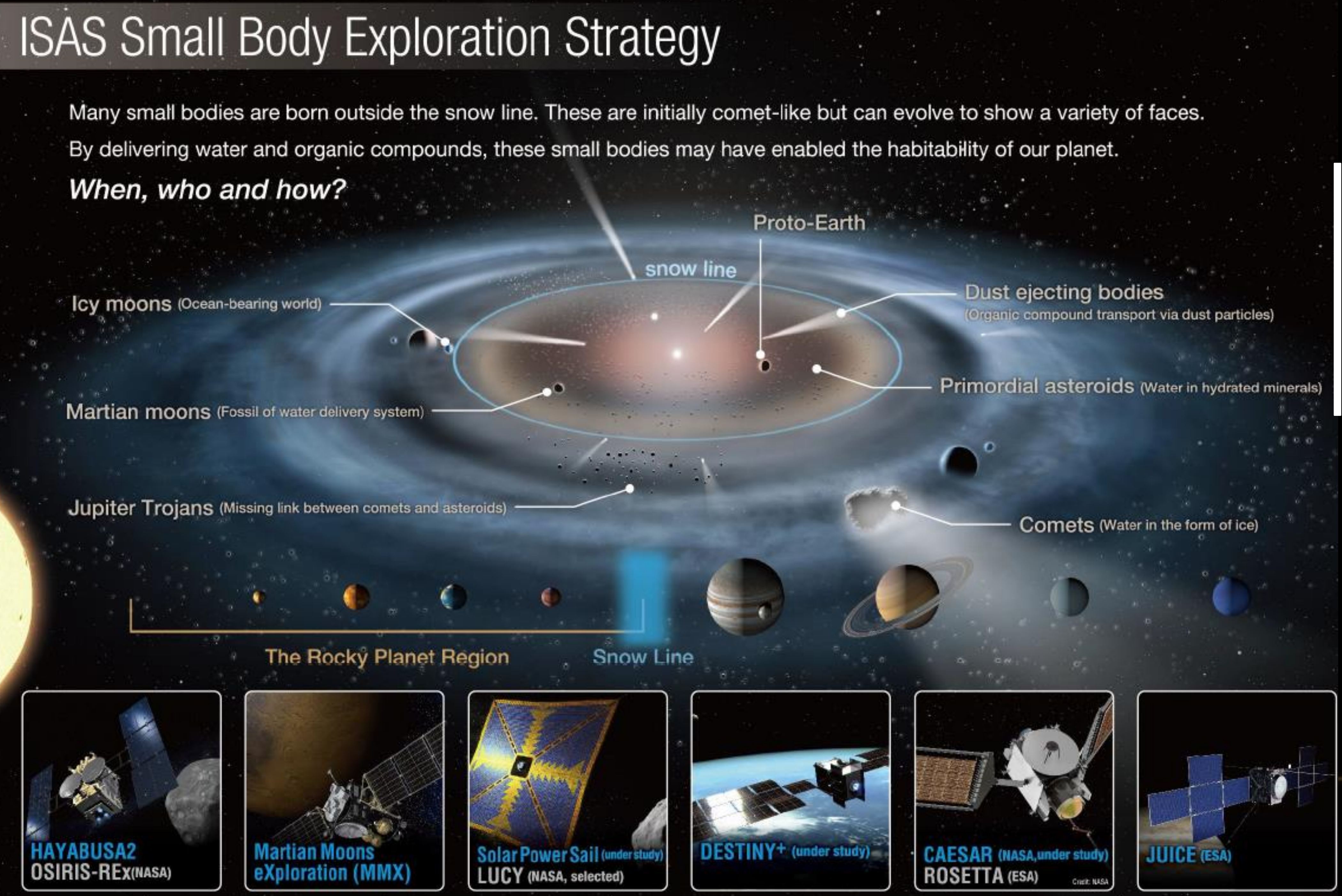
Hayabusa2 is amazingly popular among Japanese science journalists.

FAQ:

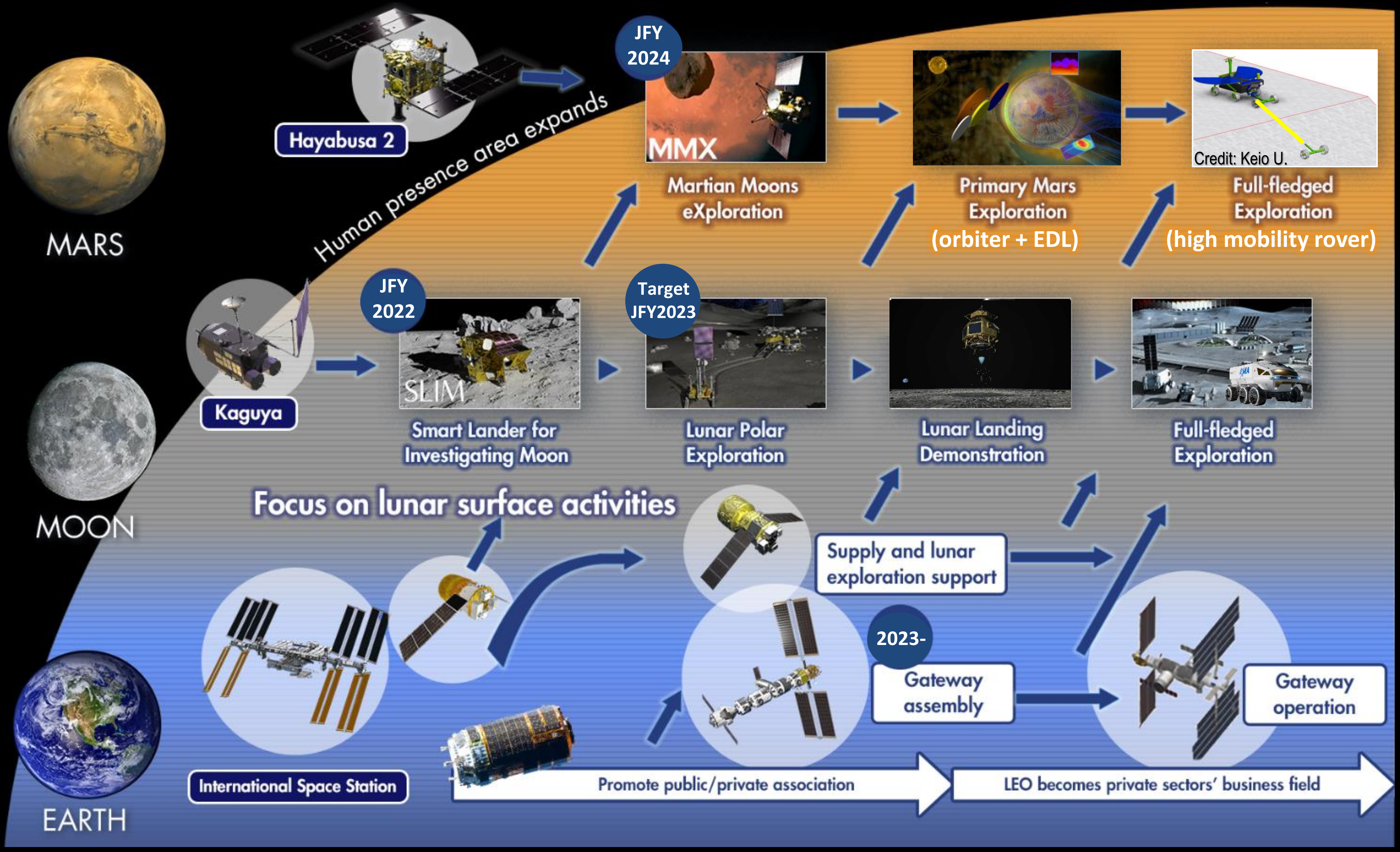
Hayabusa2 is great. Why not go for **Hayabusa3**?

We have **MMX** ongoing.

...Maybe the journalists are so smart to regard this as something different from a small body mission



JAXA's strategic small body exploration stepping into Mars program through MMX



JAXA's Overall Scenario for International Space Exploration

Leverage small body and Lunar exploration to MMX and future Mars orbiter and rover missions


MARS MISSIONS
OPERATIONAL 2001–2019
2020 AND BEYOND
Mars Odyssey (2001)
Mars Express (ESA) (2003)
Mars Reconnaissance Orbiter (2005)
MAVEN (2013)
Mars Orbiter Mission (ISRO) (2013)
Trace Gas Orbiter (ESA/RSA) (2016)
HOPE (UAE)
MMX (JAXA)
Mars moon SR by Japan
Mars Orbiter (China)
MMX complements MSR
Mars Sample Return Orbiter
Mars Sample Return Lander
Mars Lander & Rover (China)
Mars 2020 Rover (NASA)
Mars Sample Return Lander
Curiosity Rover (2011)
InSight
Mars Sample Return (China)
ExoMars Rover (ESA/RSA)
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers
U.S. Missions
non-U.S. Missions
<NASA>

MMX:
Martian Moons eXploration

Martian Moons eXploration (MMX)

Japanese next-generation sample return mission

PHASE-B STARTS IN FEBRUARY 2020

- Launch in 2024 (TBD)
- Phobos: remote sensing & *in situ* observation
- Deimos: remote sensing observation (multi-flybys)
- Retrieve samples (>10 g) from Phobos return to Earth in 2029 (TBD)

THE 1ST SAMPLE RETURN MISSION FROM THE MARTIAN SATELLITES!

MMX Science Goals

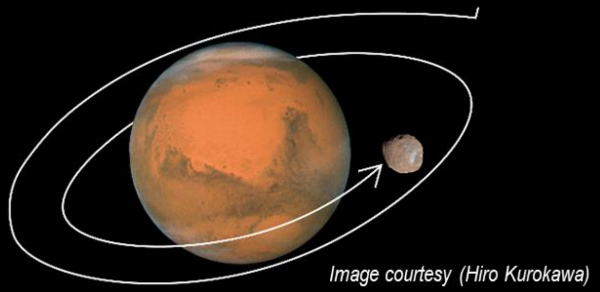
<Goal 1>

To **reveal the origin of the Martian moons**, and then to make a progress in our understanding of planetary system formation and of primordial material transport around the border between the inner- and the outer-part of the early solar system

<Goal 2>

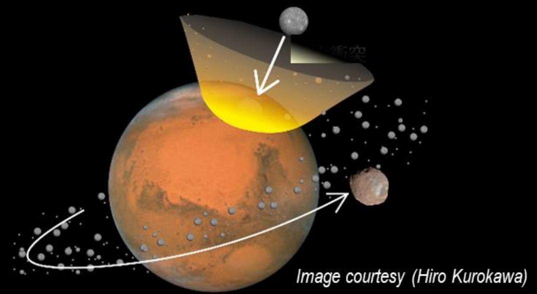
To **observe processes that have impacts on the evolution of the Mars system** from the new vantage point and to advance our understanding of Mars surface environment transition

Capture of asteroid



Consistent with D- or T-type IR spectra

***in situ* formation by an impact**



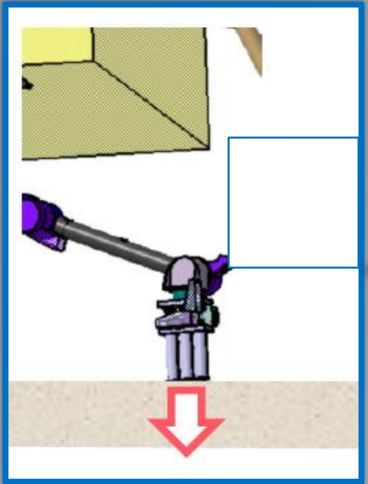
Consistent with low eccentricity & inclination

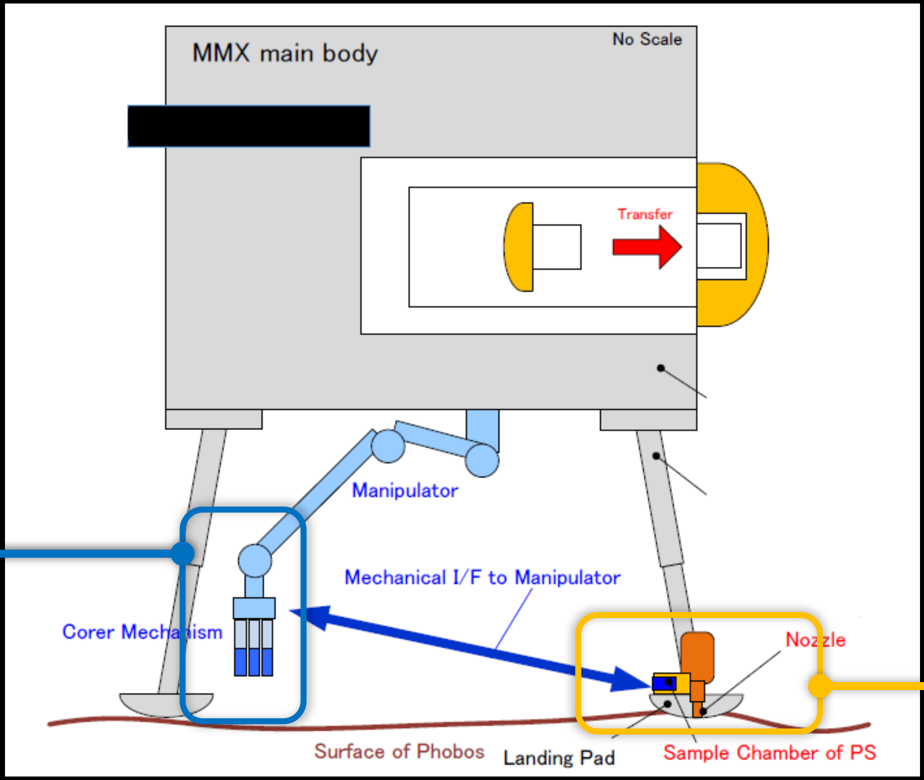
TWO SYNERGISTIC SAMPLING SYSTEMS

Coring & pneumatic sampling maximizes MMX sample science

Core sampler

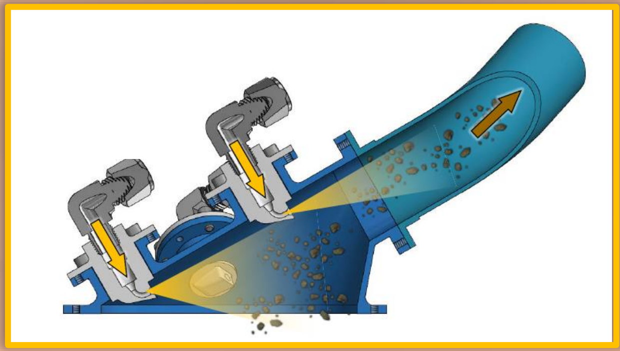
Access to <u>Phobos building blocks</u> beneath the surface (>2 cm)





Pneumatic sampler

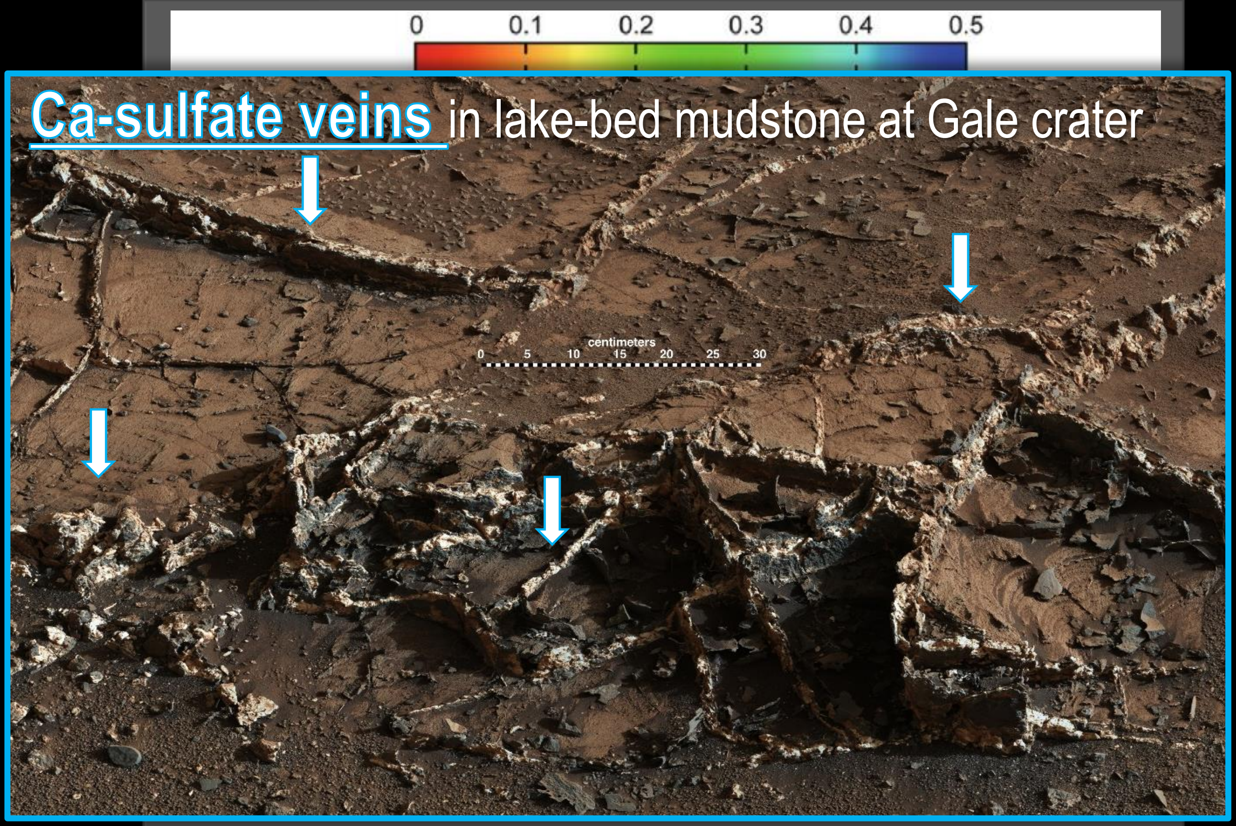
Selective sampling of <u>Phobos surface veneer</u> (incl. Martian samples!)



<preliminary design>

MARTIAN SAMPLES ON PHOBOS?

Mars impact ejecta could exist in the regolith of Phobos



Hyodo et al. (2019, Sci. Rep): Ejection velocity as a function of the peak pressure experienced during the impact and ejection process. Shadowed regions indicate ejecta capable of reaching Phobos

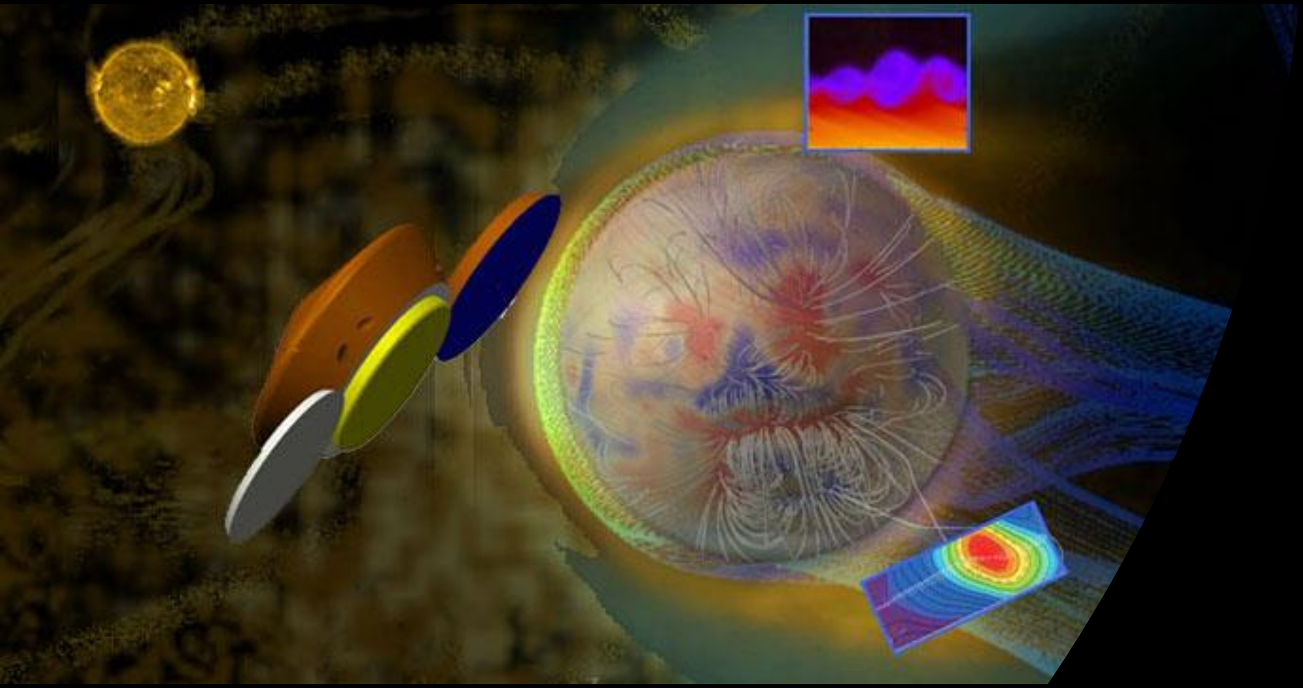
Mars ejecta on Phobos is expected to

- experience much **lower launch velocity** than Martian meteorites

  ⇒ *preserve original information?*
- contain a variety of **ancient sedimentary materials** (with organics??)

  ⇒ *cf. Martian meteorite = igneous rocks*

Phobos regolith provides a wealth of information on the ancient surface environments of Mars



What’s next after MMX?

JAXA's Mars Exploration Program (Int. Space Exp. Committee)

Goals & Objectives

Japanese Strategic Mars Exploration 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

2030s

Evolution of Water

Lander/Rover Exploration

Objectives: In-situ sample & surface science

- Petrology/Mineralogy (e.g., P-T condition)
- Geochemistry (e.g., dating, elemental abundances)
- Biochemistry (e.g., biomarker/signature, life detection)

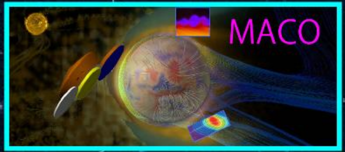
EDL

Distribution & Inventory of Water

Small Orbiter & EDL demonstration

Objectives: Global Mapping & Landing Site Selection

- Radar sounder observation of subsurface world
- Distribution, circulation & storage of water and volatiles
- Monitoring of space & surface environment (e.g., radiation)



2020s

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

Sample Return

Deep Space Transportaion

Participation of International Mars Program (e.g., MSR))

20xx

Chemical Evolution

2030s

Distribution & Inventory

post-MMX

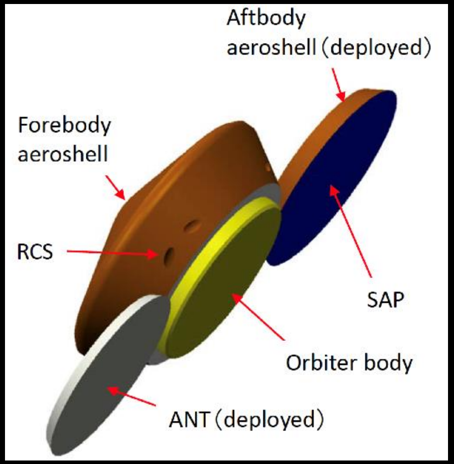
Origin & Delivery

2020s

MACO (Mars Aqueous-environment and space Climate Orbiter)

As the next step in JSMEP, we had own orbiter plan, MACO, before participation in the international MIM concept. MACO is characterized by

- Science investigation of space climate, weather, and aqueous environment
- Primary focus on distribution and inventory of water and EDL demonstration
- Close collaboration between Planetary Science and Heliophysics



The scientific value of MACO has been evaluated by broader science community: It was nominated as one of large-scale research projects of Master Plan 2017 & 2020 by Science Council of Japan (SCJ).

<u>MACO has high potential for synergy with MIM, and we are under planning to provide sub-science payloads to MIM.</u>

SCJ Master Plan 2020, Project #96 (#24-2)

周回・探査技術実証機による火星宇宙天気・気候・水環境探査計画

MACO (Mars-Aqueous-environment and space Climate Orbiter) Project

図 1. 40 億年前の火星想像図（左）と現在の火星（右）(©NASA)

火星気候変動の謎

水をたたえたハビタブル惑星から寒冷乾燥した惑星へと変遷を経た火星（図 1)。このような気候変動を引き起こすには、約 1 気圧分の二酸化炭素大気が表層環境から取り除かれる必要がある。最近の探査結果から地下に貯蔵されているとは考えにくく、宇宙空間への大気の剥ぎ取りが重要と考えられているが、大量の二酸化炭素を流出させるメカニズムはわかっていない。

図 2. 火星大気散逸機構の解明と過去 40 億年の表層環境進化への制約の相互検証がもたらす、惑星の大気進化と多様性・ハビタブル惑星の理解。

目的・学術的な意義：生命生存可能（ハビタブル）惑星成立の条件は何か？

本計画の目的は、ハビタブル環境の持続性の理解に向けて、火星における宇宙天気・気候・水環境の研究と、着陸探査に向けた探査技術実証である。特に、極端な太陽変動への瞬時応答を調べることで、過去 40 億年にわたり宇宙への大気散逸が火星の気候変動にどのような影響を及ぼしてきたのかを理解する（図 2）とともに、火星をとりまく宇宙環境の把握と、将来の着陸探査に必要な技術獲得、表層・浅部地下水環境の調査を行う。

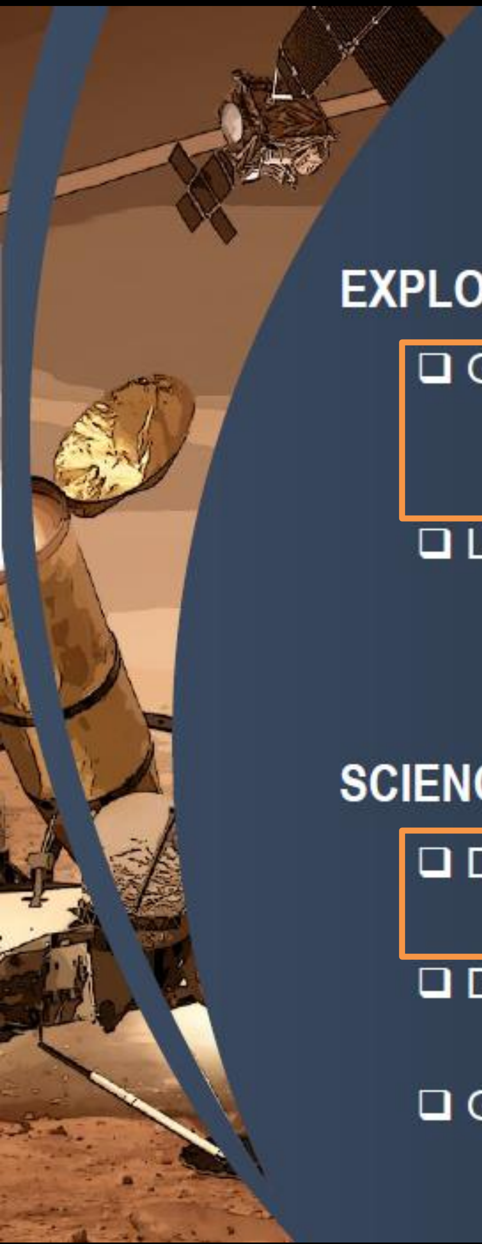
計画概要・科学コミュニティでの位置づけ

今後の太陽系探査において、生命生存可能（ハビタブル）環境の形成と進化の探求が重要な科学目標となっている（図 3)。その中で火星は、過去にハビタブルな環境を保持し、進化の過程でそれを失った地球外太陽系天体として、国際的にも重要な探査対象である。2030 年代には国際協働による火星サンプルリターン MMX が計画されており、そこで日本が主導的な役割を果たすためにも、太陽の影響を受ける大気と浅部地下環境の共進化過程に着目した我が国独自の火星探査の実施が喫緊の要請である。本研究は、国際協働宇宙探査に向けた我が国の戦略的火星探査の重要なステップとして位置づけられており（図 4)、我が国の宇宙基本計画の中の太陽系探査のプログラム化の方針とも合致している。

連絡先：関 華奈子（東京大学大学院理学研究科 Email: k.seki@eps.s.u-tokyo.ac.jp）

CommBirds (next-gen communications relay satellites in MIM) will offer attractive platform also for space weather investigation at Mars.

<u>Japanese participation in MIM will stimulate collaboration between planetary science and heliophysics communities internationally.</u>



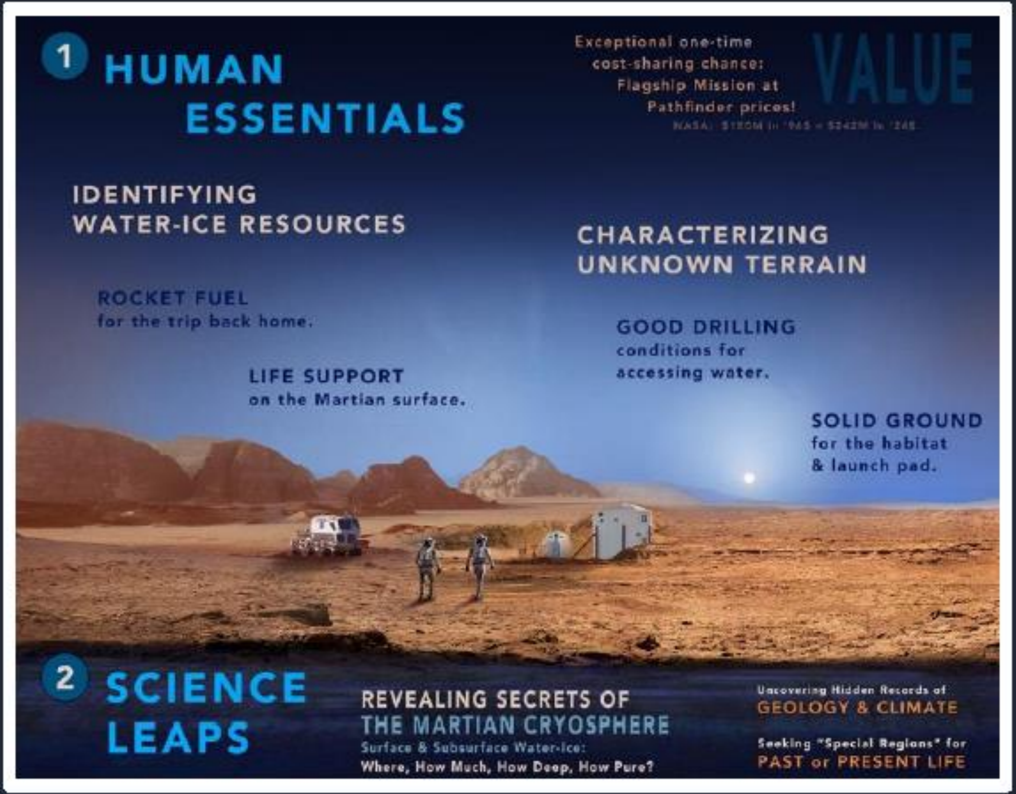
Exploration Ice Mapper: Objectives

EXPLORATION OBJECTIVES

- ❑ Ground Ice as a Resource
  - Is there water ice contained within the first 10m of the surface?
  - What are the spatial extents of the deposits?
- ❑ Landing Site Geotechnical Properties
  - How rough are the surface and shallow subsurface?
  - How compact are the potential landing sites?

SCIENCE OBJECTIVES (notional)

- ❑ Distribution & Origin of Ice Reservoirs
  - Quantify extent and volume of water ice in non-polar regions
- ❑ Dynamic Surface Processes on Mars
  - Establish role of liquid water in Recurring Slope Lineae
- ❑ Geological Evidence for Environmental Transitions
  - Evaluate fine-scale morphology in ancient terrains ("dust removal")



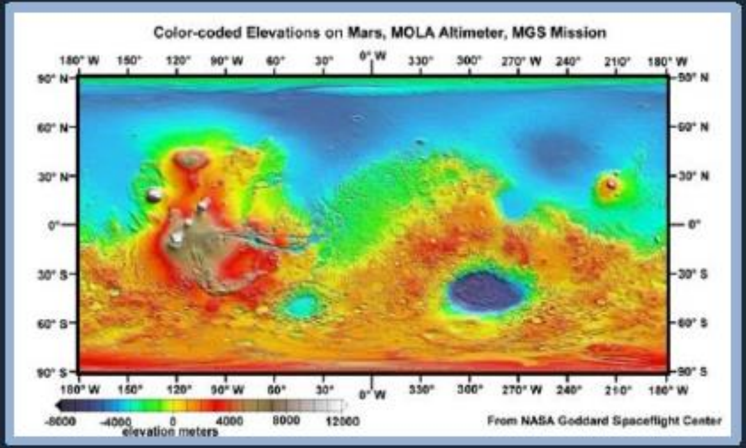
<Watzin & Haltigin, 38th MEPAG report>

Exploration Ice Mapper: Approach

"RECONNAISSANCE ZONE"

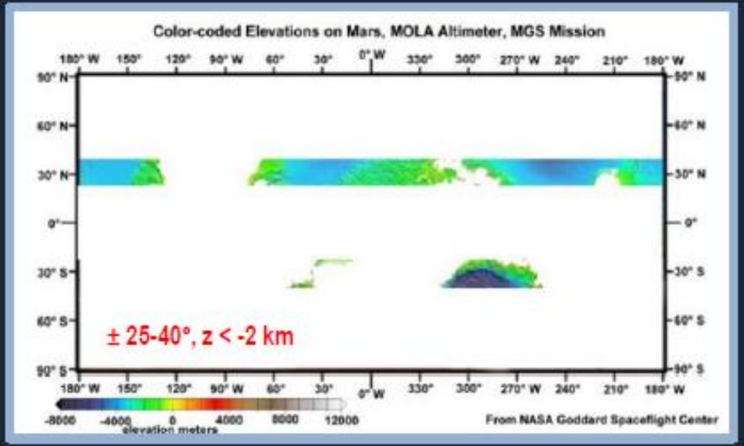
- ❑ Exploration objectives focus on regions where human landing sites may be possible
  - Equatorward of 40° for solar conditions
  - Poleward of 25° to maximize possibility of locating ground ice
  - Elevation < - 2km from MOLA datum for EDL considerations
- ❑ Science objectives – planet wide characterization

by Synthetic Aperture Radar (SAR)



KEY OUTPUTS

- ❑ Exploration: "Critical Data Products"
  - CDP-1: Reconnaissance Zone Shallow Subsurface Ice Map
  - CDP-2: Reconnaissance Zone Surface & Shallow Subsurface Physical Properties Map
- ❑ Science: "High Priority Investigations" (notional)
  - HPI-1: Martian Ice Reserves & Surface Morphologies
  - HPI-2: Radar Imaging of Recurring Slope Lineae
  - HPI-3: Ancient Mars Channel 'Excavation'
- ❑ Strengthened communication infrastructure



<Watzin & Haltigin, 38th MEPAG report>

An idea: Potential Japanese contribution to Mars Ice Mapper

Synergy Science: Provision of sub-science payloads and science collaboration

Two Science Payloads Packages to answer key questions:

- ➢ To what extent surface/subsurface water reservoirs interact with the atmosphere and have changed with time?
- ➢ How is "water" transported from surface to upper atmosphere where it photo-dissociates and escapes to space?
- ➢ What is the effects of intrinsic magnetic fields on space radiation environment and atmospheric escape from Mars?

◎ Vertical Atmospheric Coupling Package (with focus on water)

- ✓ THSS (Terahertz Band Heterodyne Spectroscopy Sensor): 3D water map and wind
- ✓ HRMS (High Resolution Mass Spectrometer): Atmospheric isotopic composition
- ✓ Ion Drift Meter and RPA: In-situ wind and temperature

The first vertically-resolved measurement of wind and water vapor in atmospheric boundary layer near surface.

◎ Martian Space Weather Package (with a focus on space radiation environment)

- ✓ MAI (Mars UV aurora/dayglow imager) Map of space radiation penetration
- ✓ Space Environment (SE) Sensors (magnetometer, electron and ion detectors, space radiation sensor) In-situ measurement of space environment

Visualization of space environment and its effects on the radiation (high-energy particles) penetration.

EDL demonstration: Accommodation of small landing probe

◎ Piggy-Bag Small Landing Probe (with deploy of small robots?)

- ✓ Meteorological observations on ground?, MSR supports?, Aerocapture for MOI?

Weather/radiation info at candidate future landing site?

JAXA's Mars Exploration Program (Int. Space Exp. Committee)

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Japanese Strategic Mars Exploration 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

Exploring Subsurface World by High Mobility Rover

2030s

Evolution of Water

Lander/Rover Exploration
Objectives: In-situ sample & surface science
- Petrology/Mineralogy (e.g., P-T condition)
- Geochemistry (e.g., dating, elemental abundances)
- Biochemistry (e.g., biomarker/signature, life detection)

EDL

Distribution & Inventory of Water

2020s

Origin

Martian Moon
Objectives: M
- Origin of Phobo
- Transportation c

SR))

20xx

Chemical Evolution

2030s

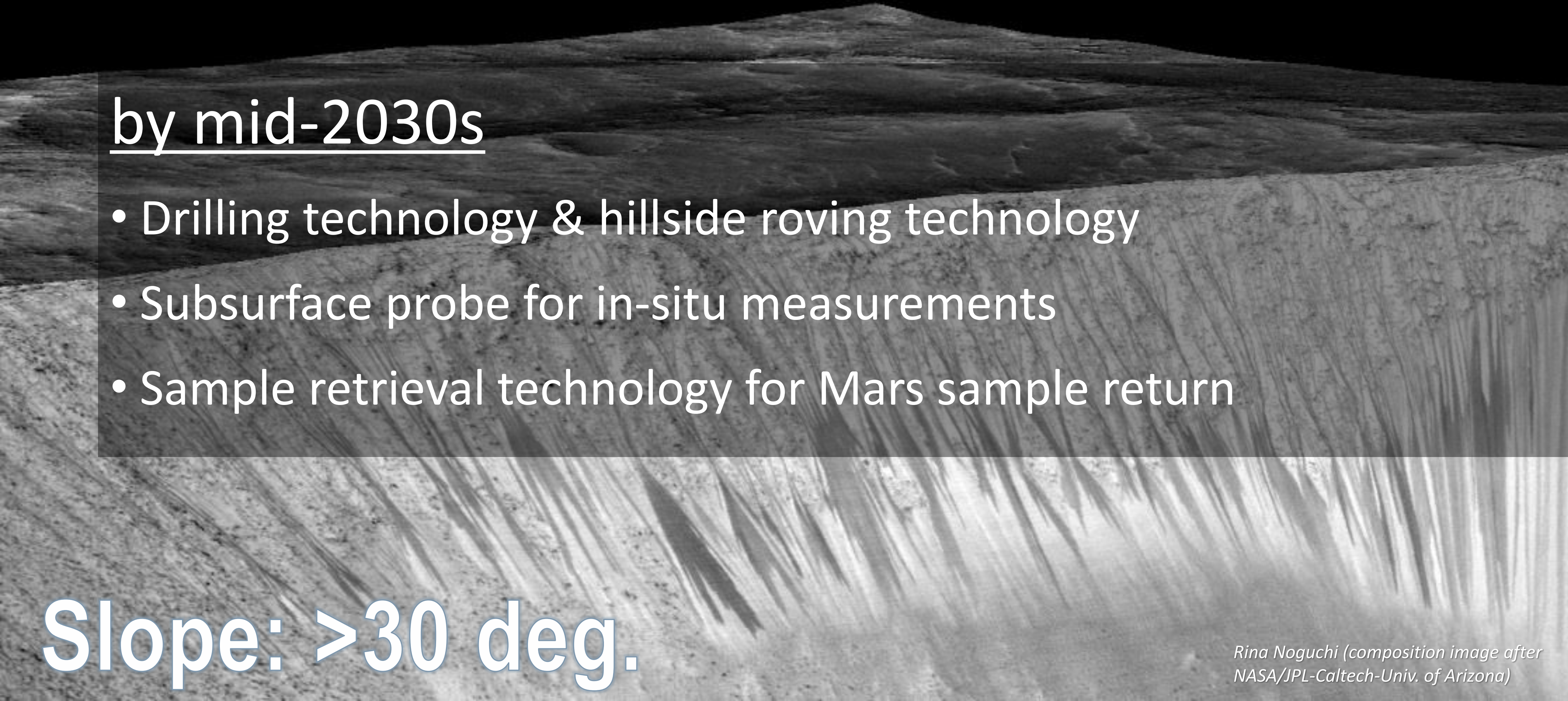
Distribution & Inventory

Origin & Delivery

2020s

An Approach for the Next Strategic Landing Mission

-Exploring Subsurface World by high mobility rover-



by mid-2030s

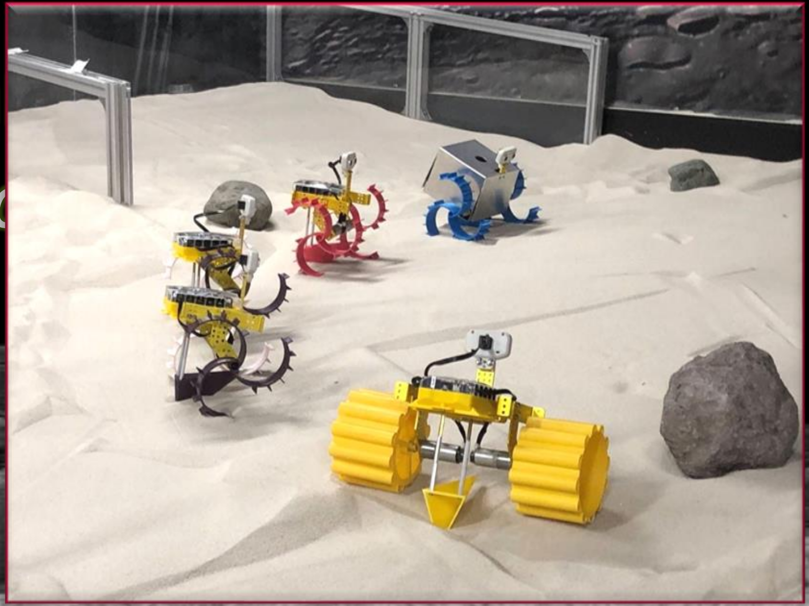
- Drilling technology & hillside roving technology
- Subsurface probe for in-situ measurements
- Sample retrieval technology for Mars sample return

Slope: >30 deg.

Rina Noguchi (composition image after NASA/JPL-Caltech-Univ. of Arizona)

ext Strategic La

World by high m



Moon-to-Mars Challenge (ISAS/JAXA student program)

JAXA's Mars Exploration Program (Int. Space Exp. Committee)

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Exploring Subsurface World by High Mobility Rover

Distribution & Inventory of Water

EDL

"Ice Mapper" mission by NASA-CSA-JAXA, etc. in late 2020s

2020s

Origin & Delivery of Water

Martian Moons Exploration (MMX)
Objectives: Mo
- Origin of Phobos
- Transportation o

MMX

Sample Return
Deep Space Transportaion

Participation of
International Mars Program (e.g., MSR))

20xx

Chemical Evolution

2030s

Distribution & Inventory

Origin & Delivery

2020s