Martian Moons eXploration (MMX)

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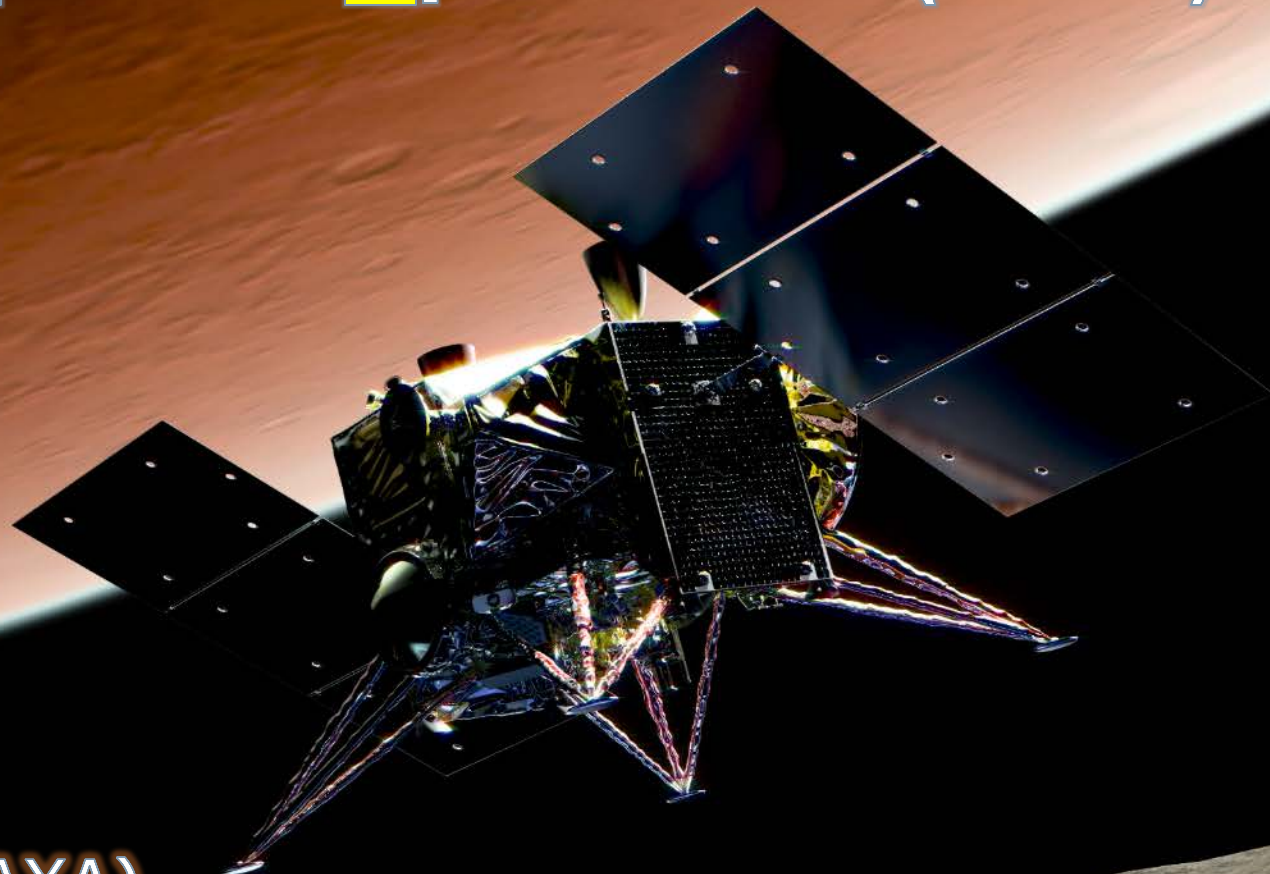

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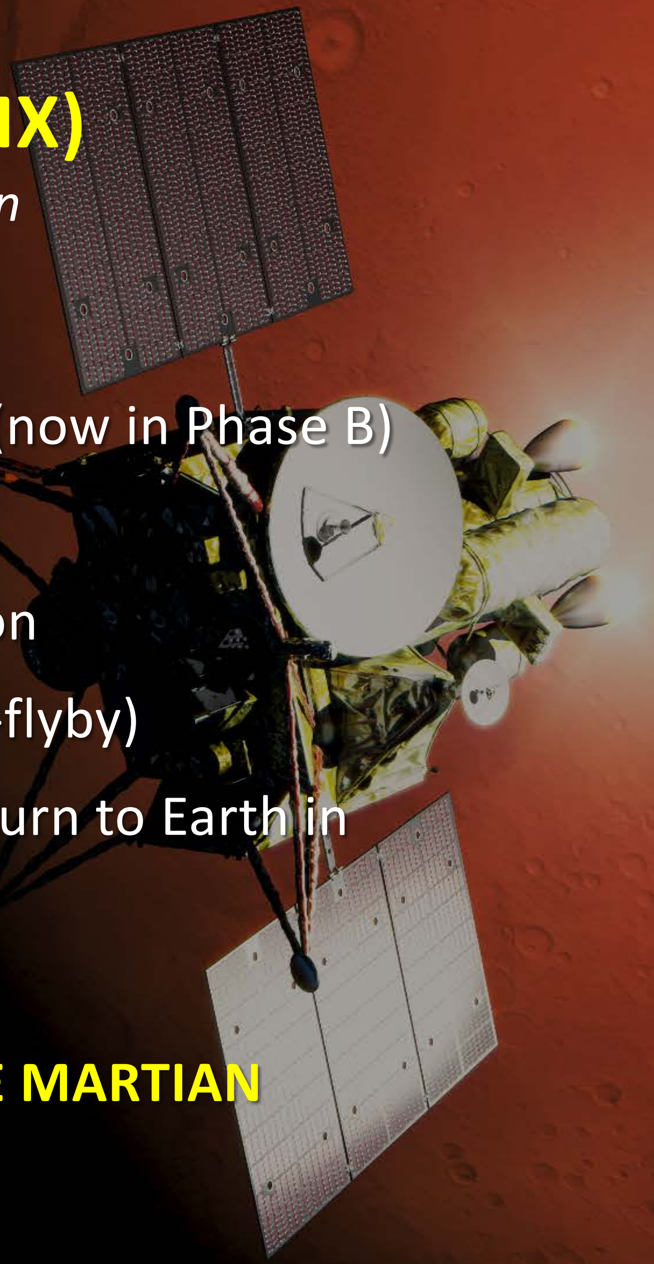
MMX Science Team

MMX Project Team

Martian Moons eXploration (MMX)

Japanese next-generation sample return mission



- JAXA officially approved MMX in Feb. 2020 (now in Phase B)
- Launch in 2024
- Phobos: remote sensing & *in situ* observation
- Deimos: remote sensing observation (multi-flyby)
- Retrieve samples (>10 g) from Phobos & return to Earth in 2029

THE 1ST SAMPLE RETURN MISSION FROM THE MARTIAN SATELLITES!

WHY PHOBOS AND DEIMOS?

Regolith of Phobos/Deimos contains Martian building blocks, impactors, late accreted volatiles, ancient Martian surface components etc…

- **Constrain the initial condition of the Mars-moon system**
- **Gain vital insight and information on the source(s) and delivery process of water (& organics) into Mars and the inner rocky planets**

MMX Science Goals

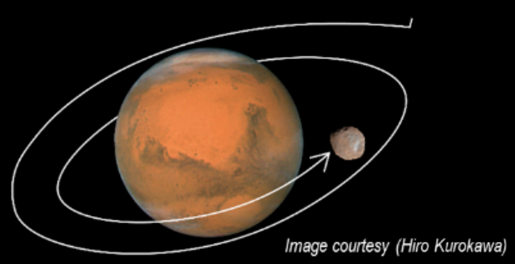
<Goal 1>

To <u>reveal the origin of the Martian moons</u>, 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>

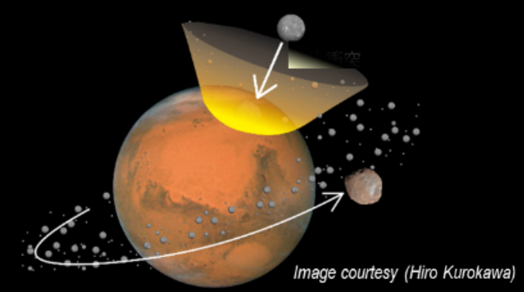
To <u>observe processes that have impacts on the evolution of the Mars system</u> from the new vantage point and to advance our understanding of Mars surface environment transition

Capture of asteroid



Consistent with D- or T-type IR spectra

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

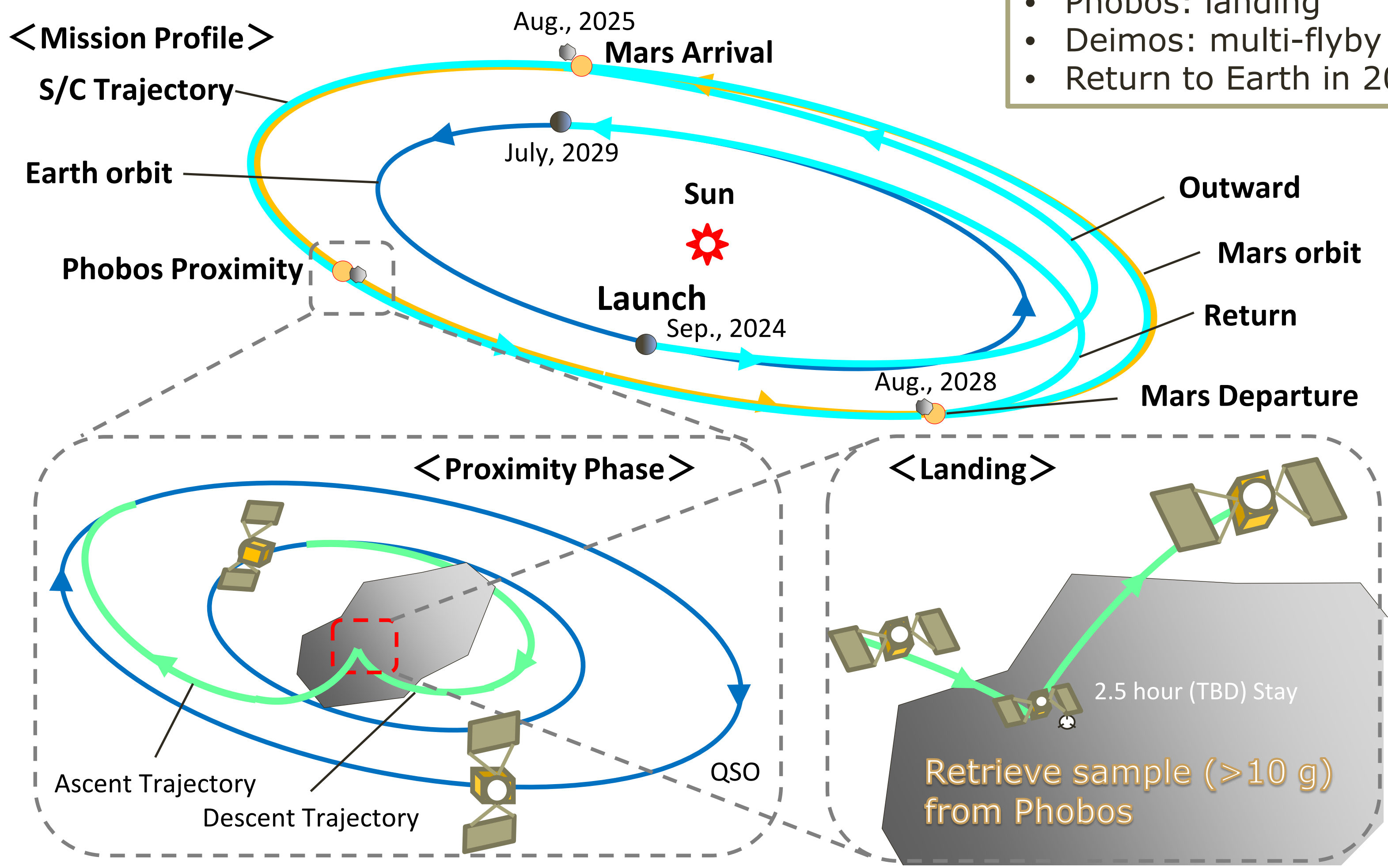


Consistent with low eccentricity & inclination

Mission Profile

- The total of 5 years trip by use of chemical propulsion system
- Interplanetary flight: 1 year for outward/homeward
- Stay at curcum-Mars orbits 3 years

- Launch in 2024
- Phobos: landing
- Deimos: multi-flyby
- Return to Earth in 2029

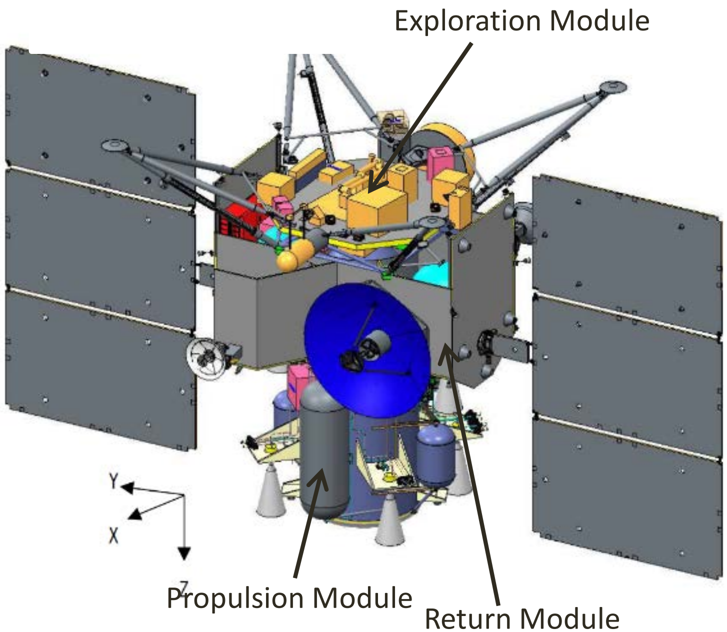


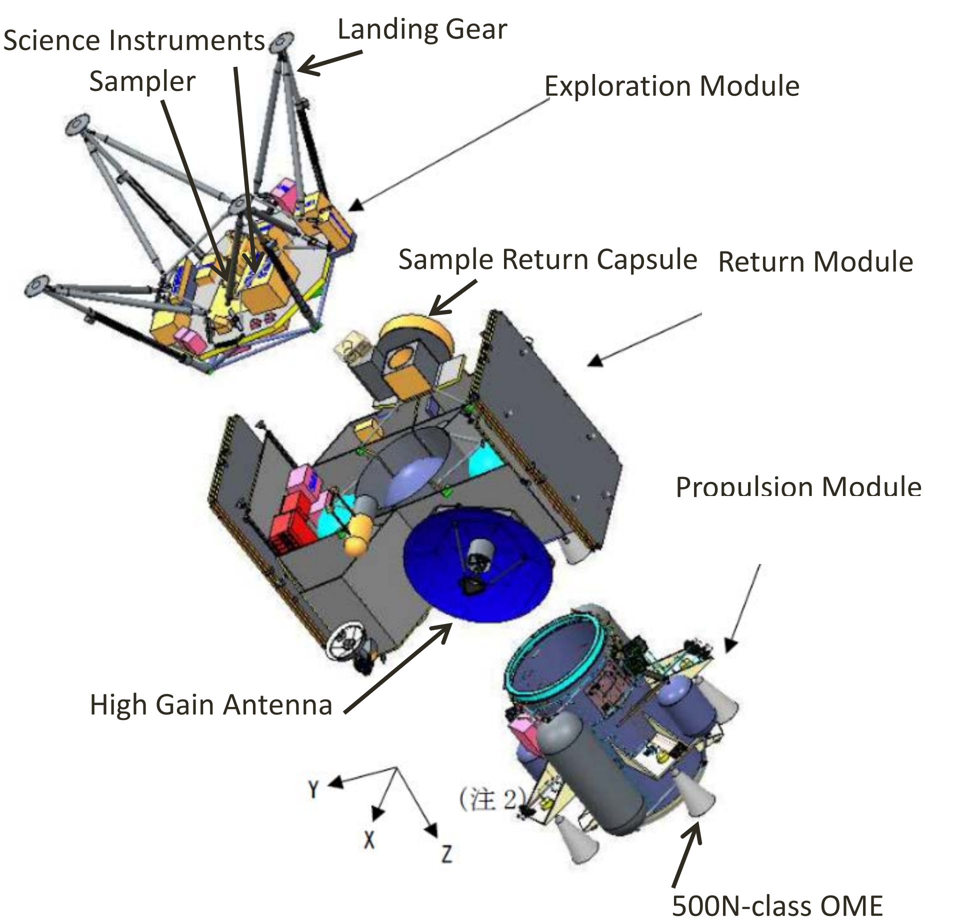
(written above is an example, and could change in the future)

Spacecraft Configuration

As a result of Phase-A study, spacecraft system's configuration and major specification are defined preliminarily

On-Orbit Configuration





Launch Mass : 4000kg

Three stages system.

Return module: 1780kg

Exploration module: 330kg

Propulsion module: 1890kg

Mission Duration : 5 years

(written above is an example, and could change in the future)

Launch Configuration

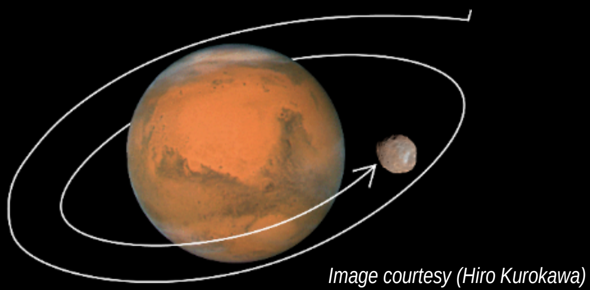
Nominal Science Payload

Payload	Measurements
Wide-angle multiband camera (OROCHI)	• Global mapping of hydrated minerals, organics, and the spectral heterogeneity of the Martian moons • Characterize the material distribution around the sampling sites
Telescopic camera (TENGOO)	• Determine the global topography and surface structure of the Martian moons • Characterize the topography around the sampling sites
Gamma-ray, neutron spectrometer (MEGANE) (*provided by NASA*)	• Determine the elemental abundance beneath the surface of the Martian satellites (Provided by NASA)
Near-infrared spectrometer (MIRS) (*provided by CNES*)	• Global mapping of minerals, molecular H_2O and organics of the Martian moons. • Characterize the material distribution around the sampling sites
Light detection and ranging (LIDAR)	• Determine the Phobos shape and topography
Circum-martian dust monitor (CMDM)	• Detect and monitor: 1) the circum-Martian dust ring; 2) interplanetary dust; 3) Interstellar dust
Mass spectrum analyser (MSA)	• Determine the mass and energy of ions from Phobos, Mars and Sun
Rover's payloads (*by CNES/DLR*) : Raman, radiometer, cameras	• Determine surface composition and physical properties

ORIGIN OF PHOBOS AND DEIMOS

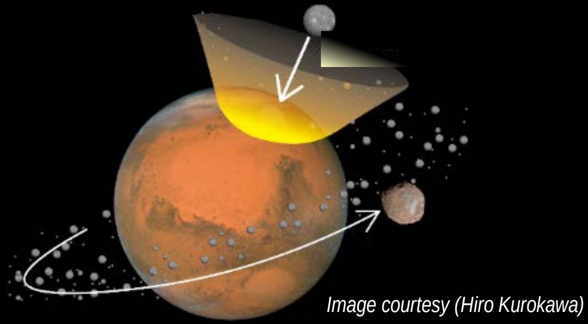
Two competing hypotheses are proposed for their origins

Capture of asteroid



Consistent with D- or T-type IR spectra

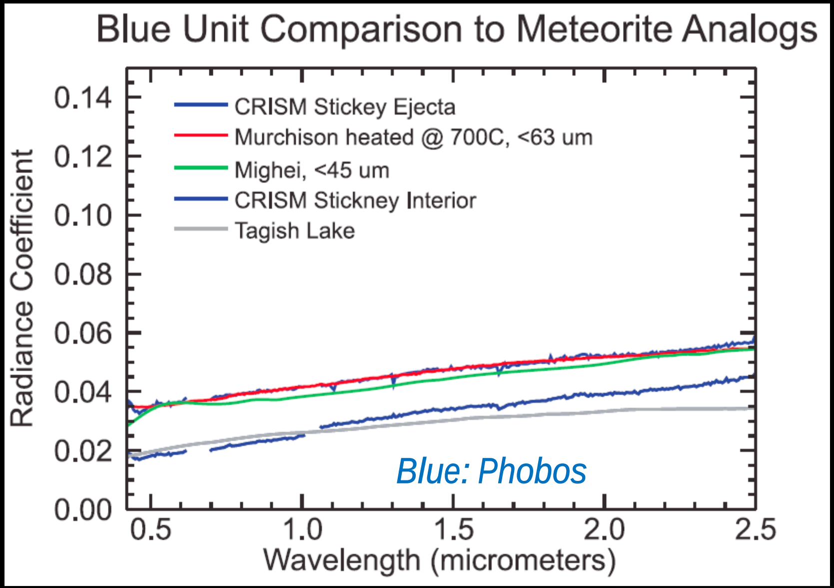
in situ formation by an impact



Consistent with low eccentricity & inclination

ORIGIN OF PHOBOS AND DEIMOS

D- or T-type spectrum is consistent with the capture origin



Fraeman et al. (2012)

If Phobos & Deimos are "giant impact origin", the spectra reflect either

- impact-related "dark" glassy debris, or
- thin surface veneer of regolith, or
- result of space weathering

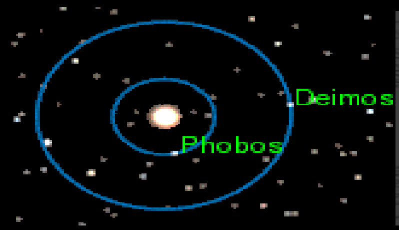
will be tested by MMX

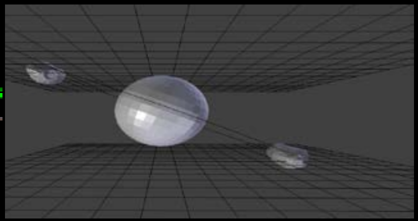
- gamma-ray & neutron, sample analysis

ORIGIN OF PHOBOS AND DEIMOS

Low eccentricity and low inclination suggest the impact origin

- Low eccentricity (Jacobson & Lainey, 2014)
  - Phobos: 0.001511, Deimos: 0.00027
- Low inclination (Jacobson & Lainey, 2014)
  - Phobos: 1.076 deg, Deimos: 1.789 deg





If Phobos & Deimos are "capture origin"...

"Gold mine" for astrophysicists!
New dynamical model to reconcile

REMOTE SENSING OBSERVATIONS

Visible & Near-infrared spectroscopy

e.g., MIRS from LESIA, France

- Spectrum range: 0.9-3.6 μm

  cf. OH = ~2.7 μm, H_2O-ice = ~3-3.2 μm, organics = 3.3-3.5 μm
- Spatial resolution: 7 m/pix @ 20 km (tentative)

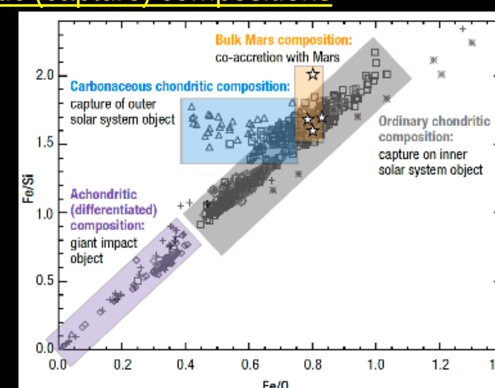
Distribution of "blue" and "red" units on Phobos (by MRO)

Gamma-ray & Neutron spectroscopy

MEGANE from APL, USA

- Elements: Mg, Fe, O, Si, Na, K, Ca, Th, U, H, C, and Cl
- Penetration depth: up to ~1 m

Fe/Si/O differentiates achondritic (giant impact) and chondritic (capture) compositions

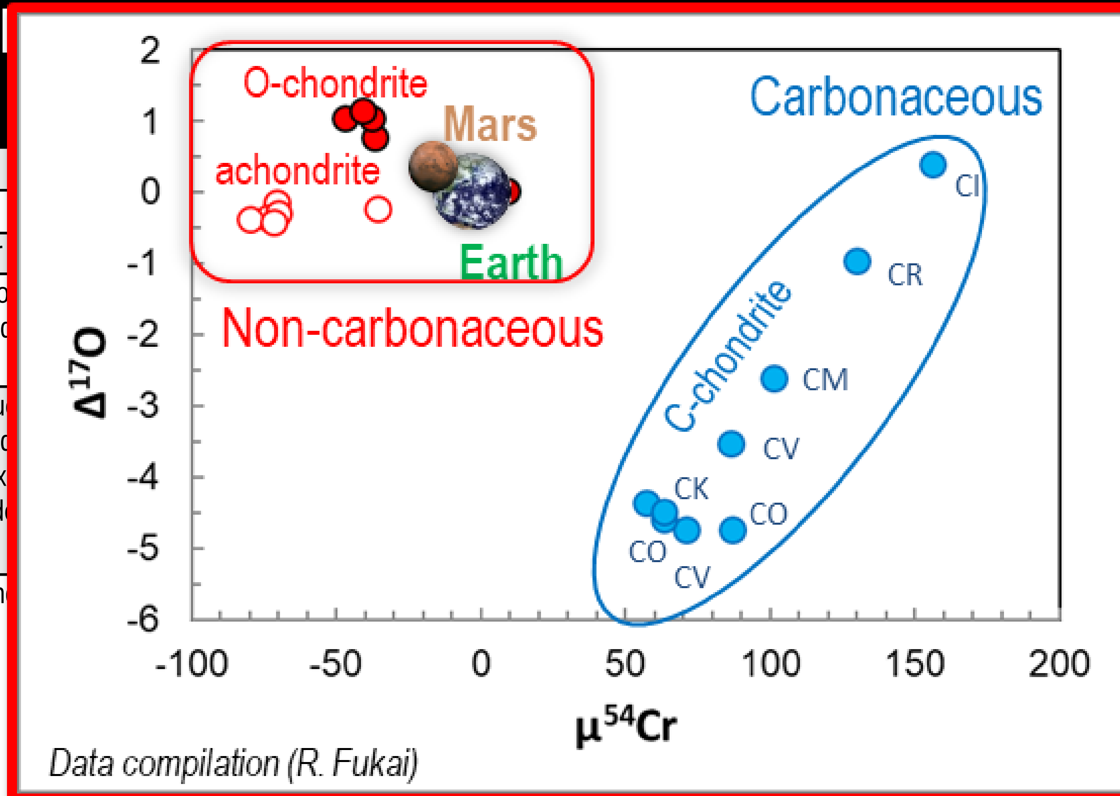


EXPECTED CHARACTERISTICS OF PHOBOS SAMPLE

	Moon origin			
	capture of asteroid		In-situ formation	
	Outer solar system body	Inner solar system body	Co-accretion	Giant impact
Petrology	Analogous to carbonaceous chondrite, IDP, or cometary material	Analogous to ordinary chondrite	?	Glassy or recrystallized igneous texture
Mineralogy	Rich in oxidized and hydrous alteration phases (e.g. phyllosilicate, carbonates), amorphous silicate	Reduced and mostly anhydrous phases (e.g., pyroxene, olivine, metal, sulfides)	Un-equilibrated mixture of chondritic minerals?	High-T igneous phases (e.g., pyroxene, olivine), Martian crustal (evolved igneous) & mantle (high-P) phases
Bulk chemistry	Chondritic, volatile-rich (e.g. high C and high H)	Chondritic, volatile poor	Chondritic (= ~ bulk Mars?) with nebula-derived volatile?	Mixture of Martian crustal (mafic) and mantle-like (ultramafic) composition possibly with impactor material (high HSE?). Degree of volatile depletion varies due to impact regime
Isotopes	Carbonaceous chondrite signature (e.g., Δ17O, ε54Cr, ε50Ti, εMo, noble gases), primitive solar-system volatile signature (e.g., D/H, 15N/14N)	Non-carbonaceous chondrite signature (e.g., Δ17O, ε54Cr, ε50Ti, εMo, noble gases), primitive (e.g., chondritic D/H, 15N/14N)?	Bulk-Mars (?) signature (e.g., Δ17O, ε54Cr, ε50Ti, εMo), planetary volatile (e.g., intermediate D/H, low15N/14N?)?	Mixture of Martian and impactor (carbonaceous or non-carbonaceous) composition, highly mass fractionated planetary volatile (e.g., low D/H, low15N/14N)?
Organics	Primitive organic matter, volatile & semi-volatile organics, soluble organics?	Non-carbonaceous signature?	?	?

(Usui et al. *Space Sci. Rev. in press*)

EXPECTED CHARACTE



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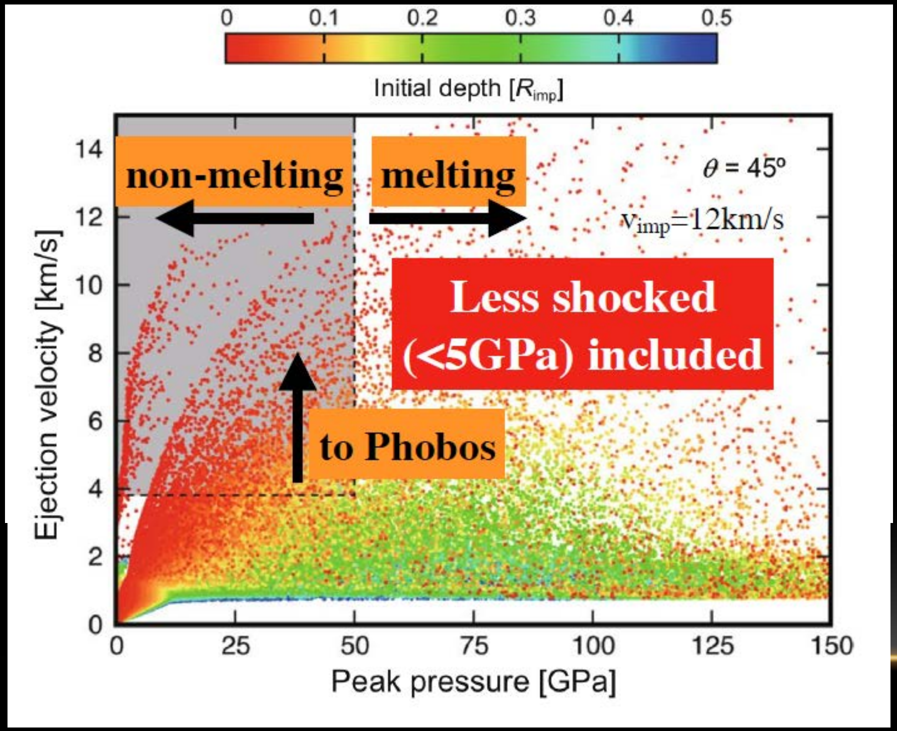
MARTIAN SAMPLES ON PHOBOS?

Mars impact ejecta could exist in the regolith of Phobos

Spray of impact ejecta on the Phobos orbit



(Hyodo et al. *2019*)

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

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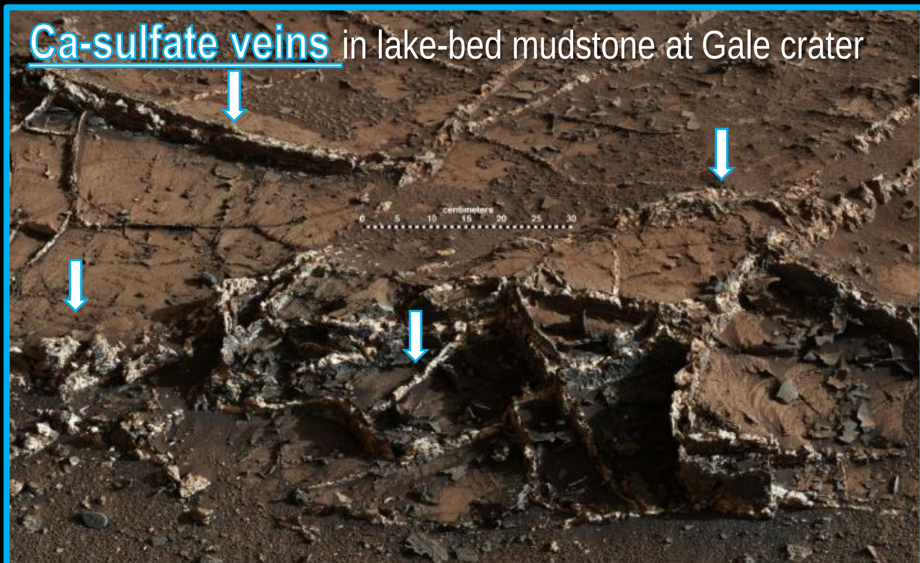

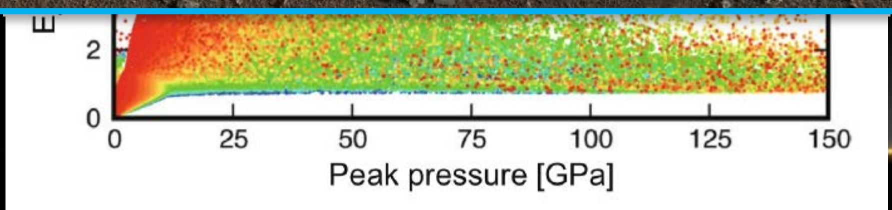

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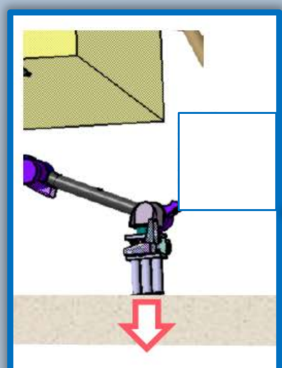
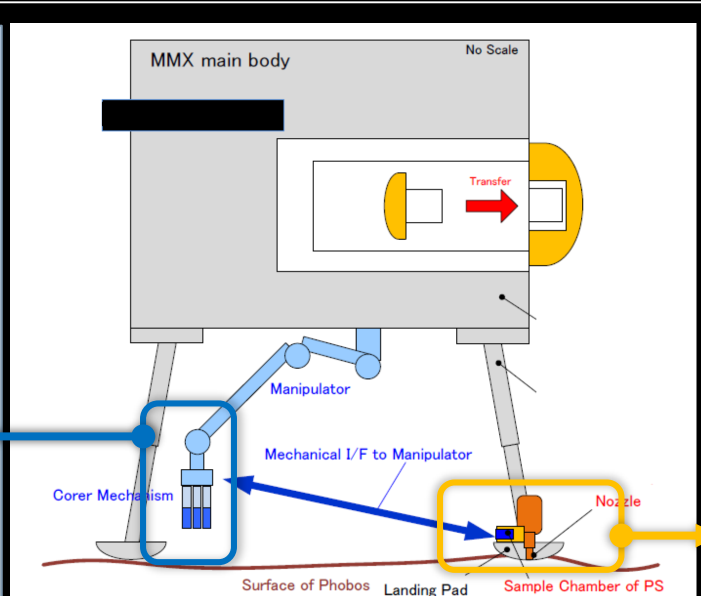
TWO SYNERGISTIC SAMPLING SYSTEMS

Coring & pneumatic sampling maximizes MMX sample science

Core sampler

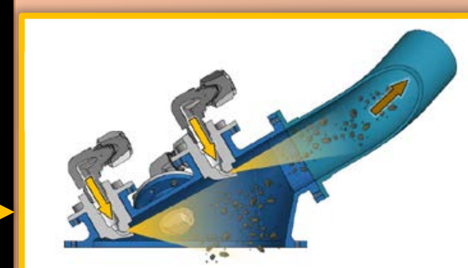
Access to Phobos building blocks beneath the surface (>2 cm)





Pneumatic sampler

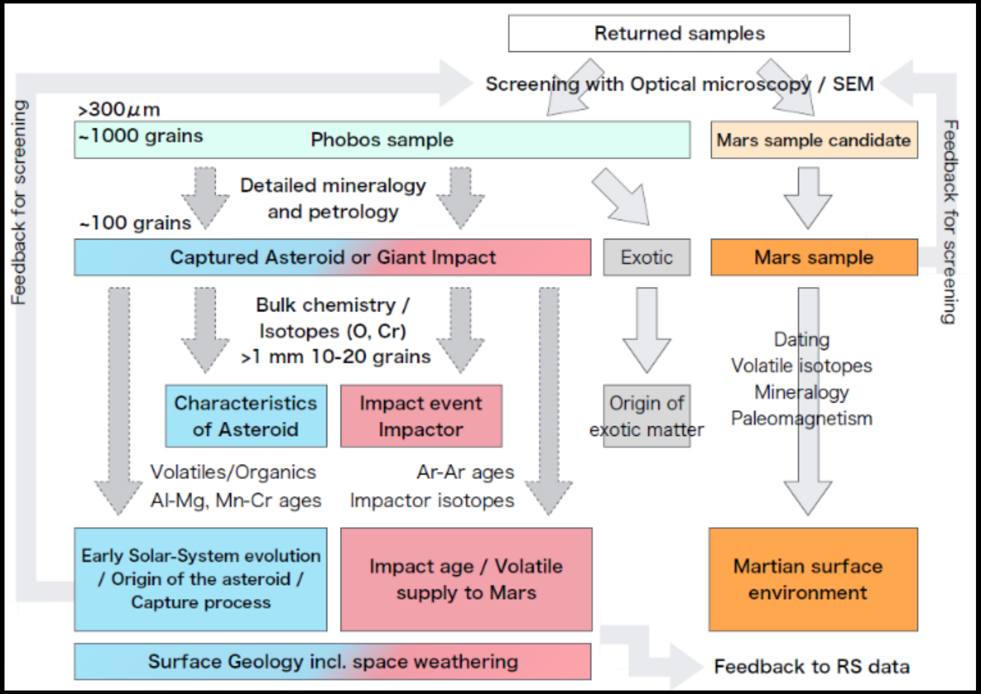
Selective sampling of Phobos surface veneer (incl. Martian samples!)



SAMPLE ANALYSIS: FLOW CHART

- ~10,000 grains for initial screening
  FYI: ~10,000 grains = ~1 g (for ~0.3 mm size grain)
- ~100 grains for detailed petrology, mineralogy, *in situ* isotope analyses
- ~10 to 20 grains for bulk isotope analyses

~1 g for the MMX team
>9 g for the int. community!



CONCLUSIONS

- The MMX spacecraft is scheduled to be launched in 2024, and return >10 g of Phobos regolith back to Earth in 2029
- The origin(s) of Phobos and Deimos has been in debate: captured asteroid or in situ formation by impact
- MMX will provide clues to their origins and offer an opportunity to directly explore the building blocks, juvenile crust/mantle components, and late accreted volatiles of Mars

MMX will constrain the initial condition of the Mars-moon system,
and shed light on the source, timing and delivery process of water (& organics) into the inner rocky planets