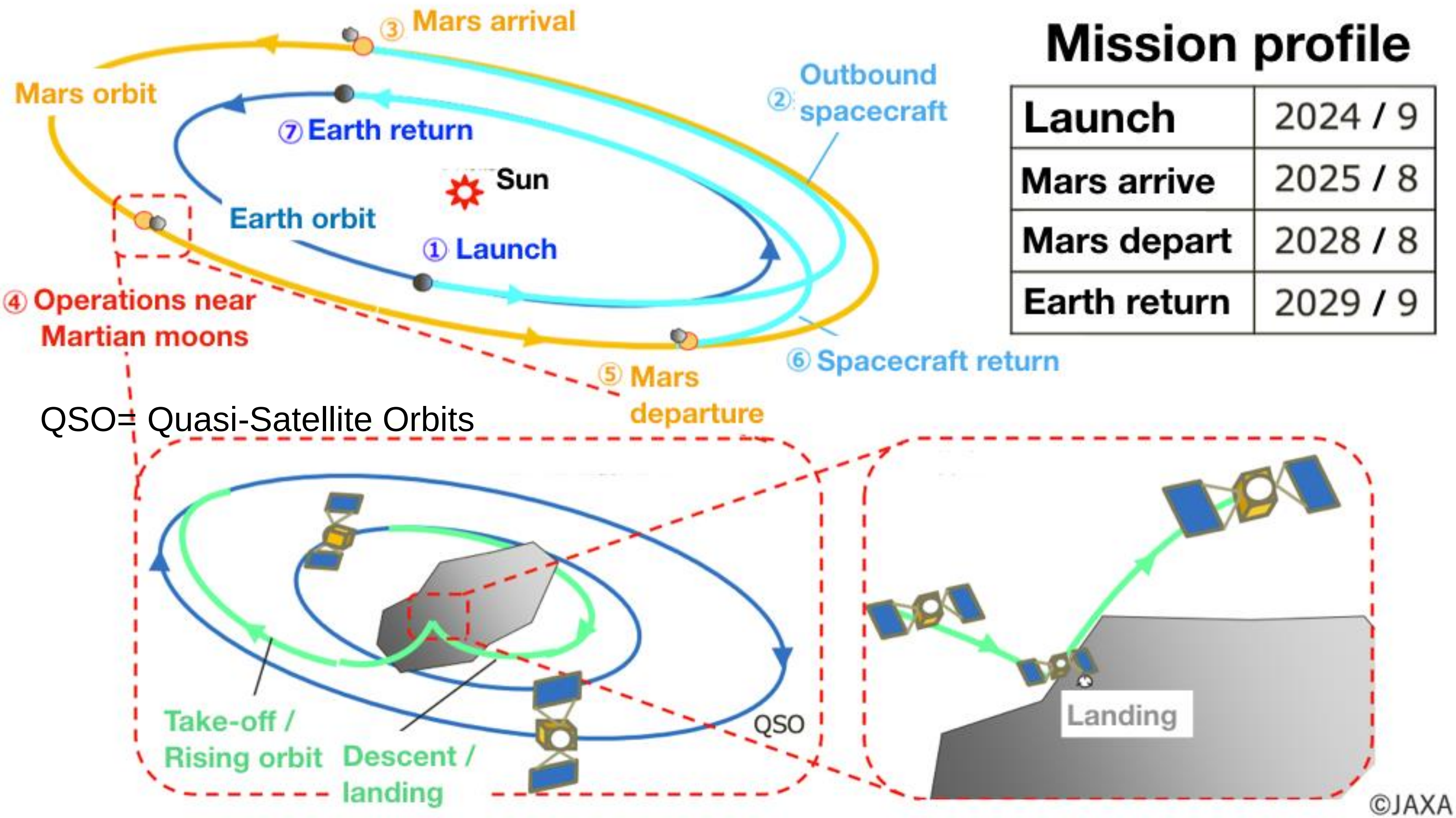
MIRS imaging spectrometer for the Martian Moon Explorer (MMX) mission

Sonia Fornasier & the MIRS team

MMX - Martian Moons eXploration mission



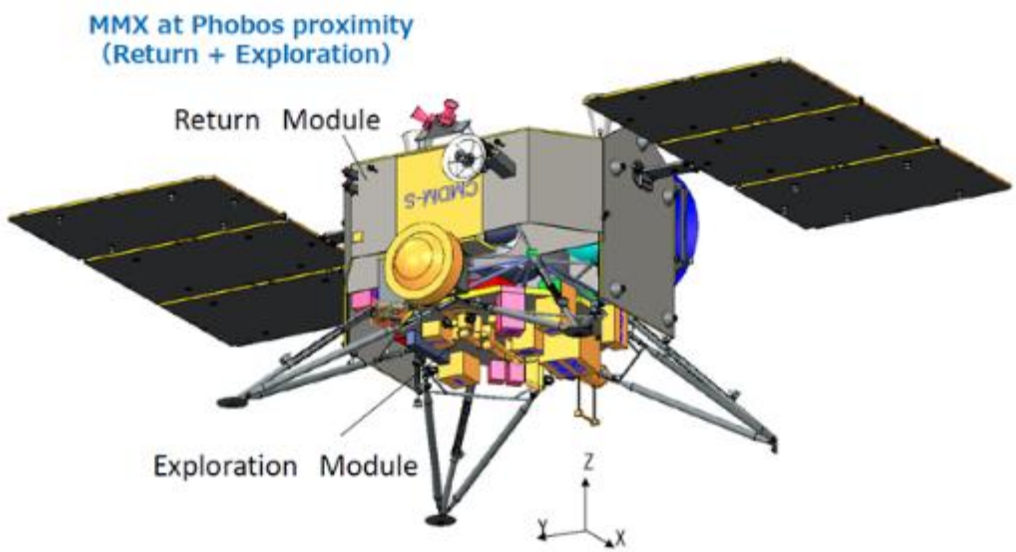
QSO= Quasi-Satellite Orbits

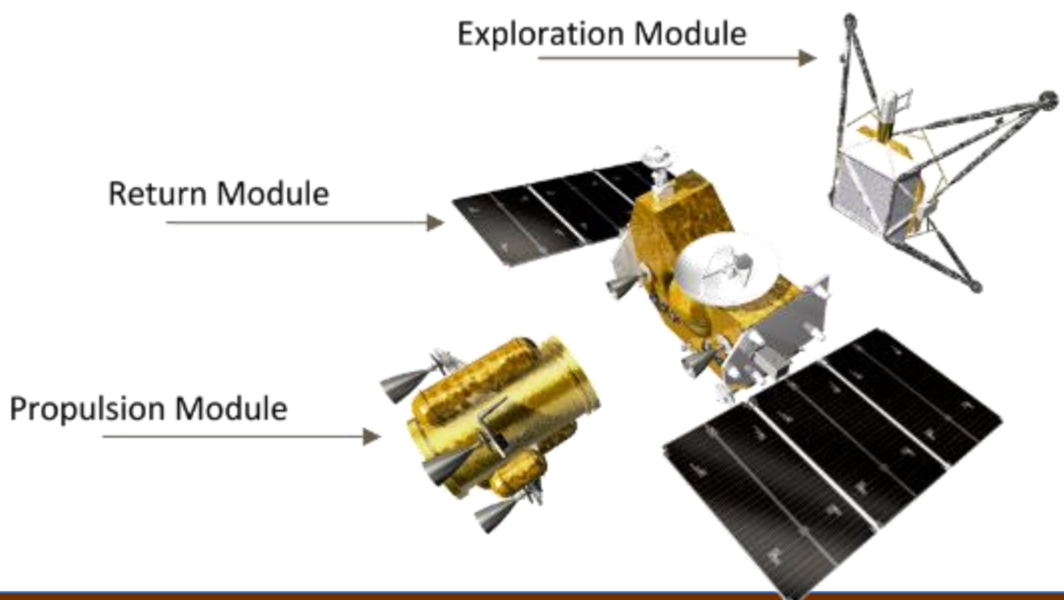
Mission profile

Launch	2024 / 9
Mars arrive	2025 / 8
Mars depart	2028 / 8
Earth return	2029 / 9

The spacecraft landing for several hours to collect a sample of at least 10g using a corer that can gather material from a minimum of 2cm below the moon’s surface.

MMX probe





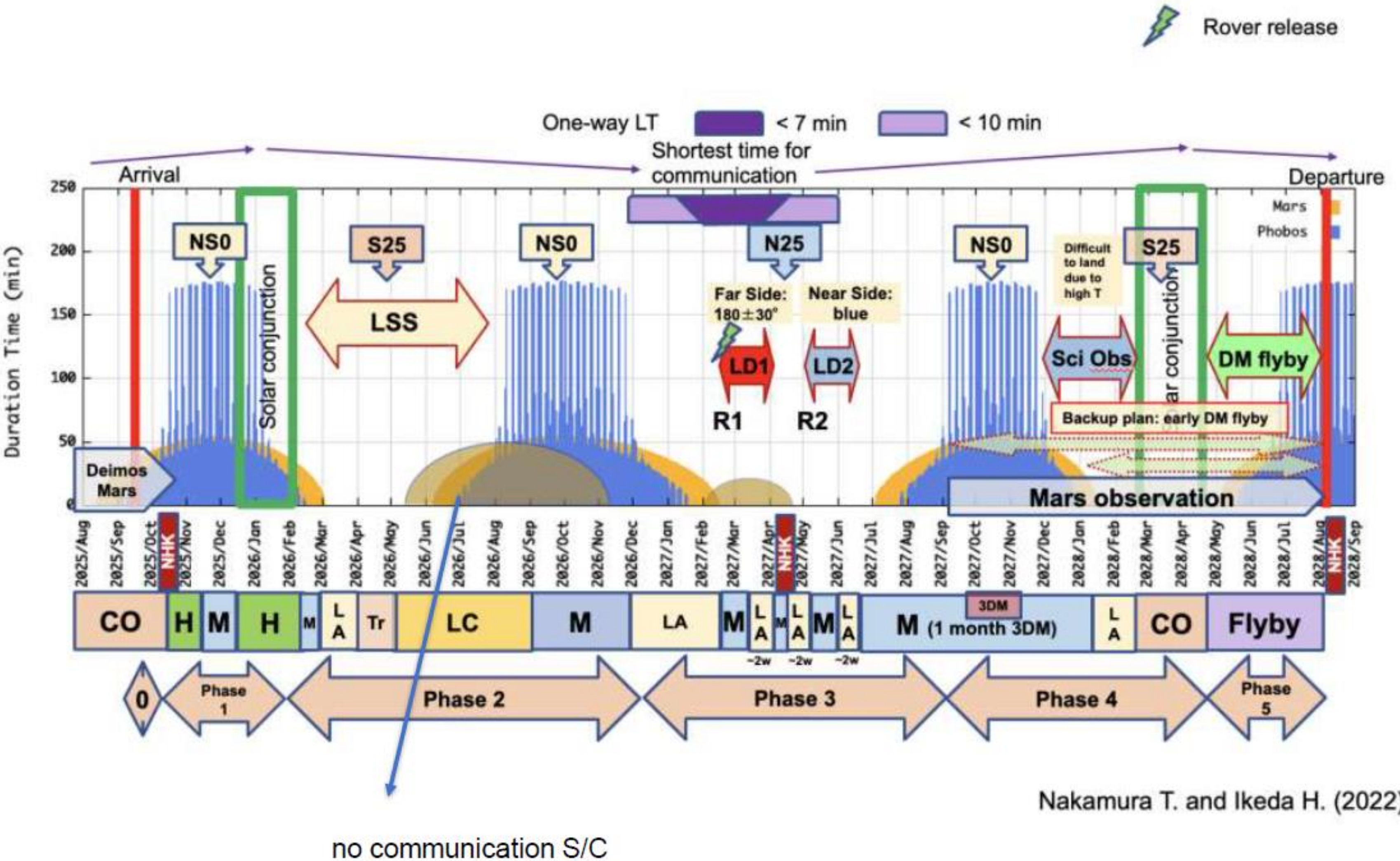
INSTRUMENTS:

MIRS Near-Infrared Imaging Spectrometer (0.9 - 3.6 μm) - CNES
MEGANE Gamma rays and Neutrons Spectrometer - NASA
OROCHI Optical Radiometer composed of Chromatic Imagers
TENGOO Telescopic Nadir Imager for Geomorphology
LIDAR Light Detection and Ranging
CMDM Circum-Martian Dust Monitor
MSA Mass Spectrum Analyzer

+ ROVER (CNES, DLR)

Science Operation Plan

- Blue and orange: eclipses of SC by Phobos and Mars



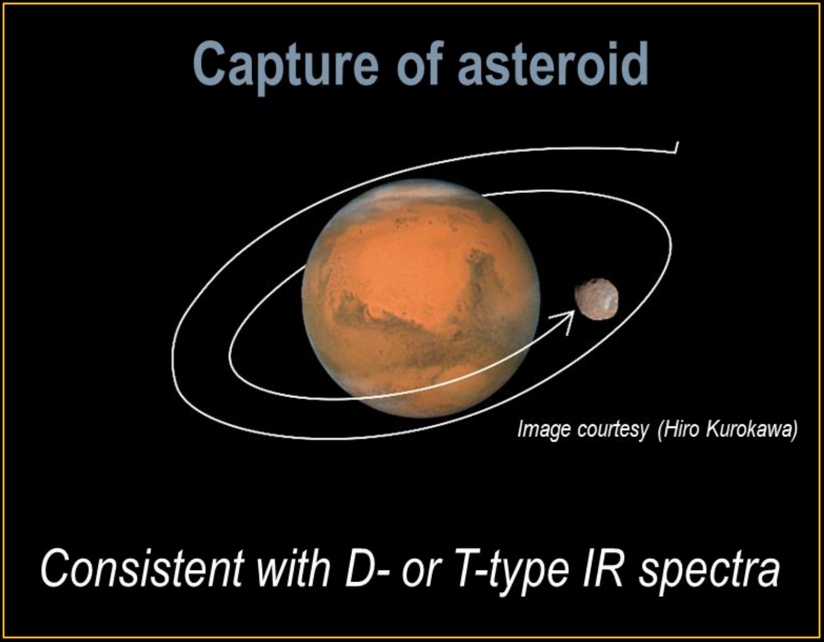
Nakamura T. and Ikeda H. (2022)

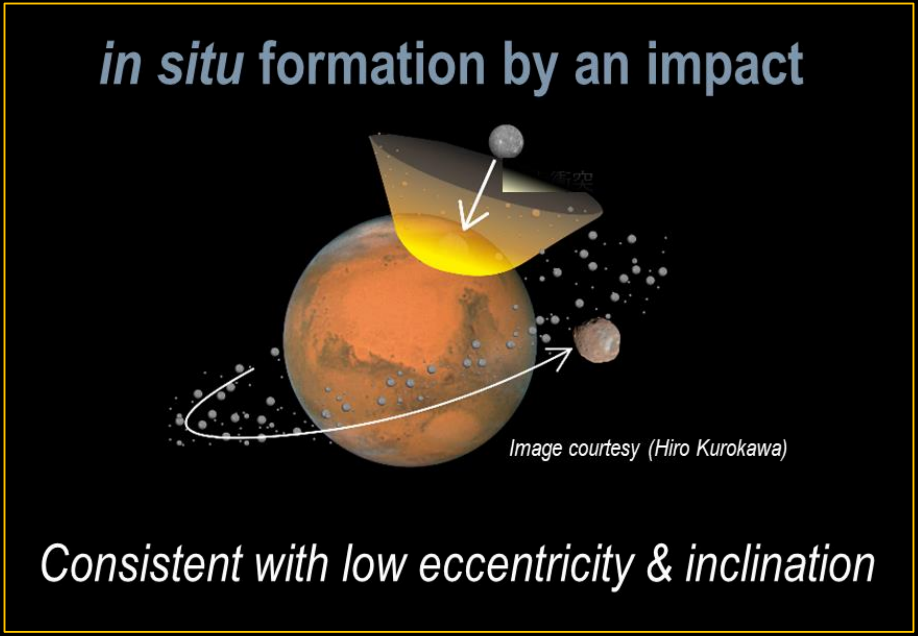
Phobos & Deimos origin

2 hypothesis:

1) Primordial asteroids (D-type) captured by Mars

2) Formed in-situ by a giant impact



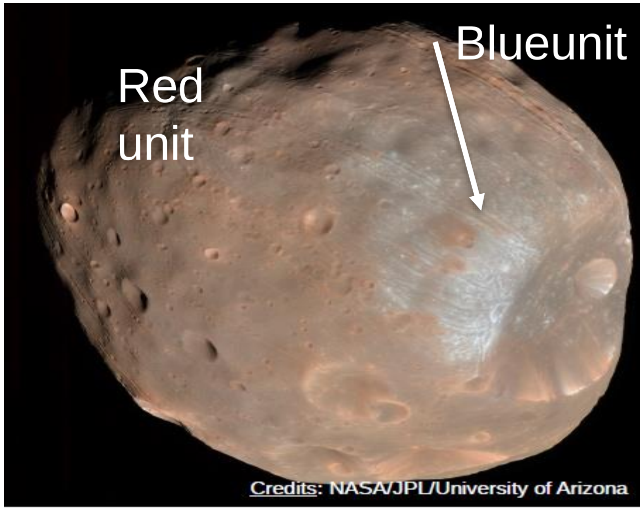


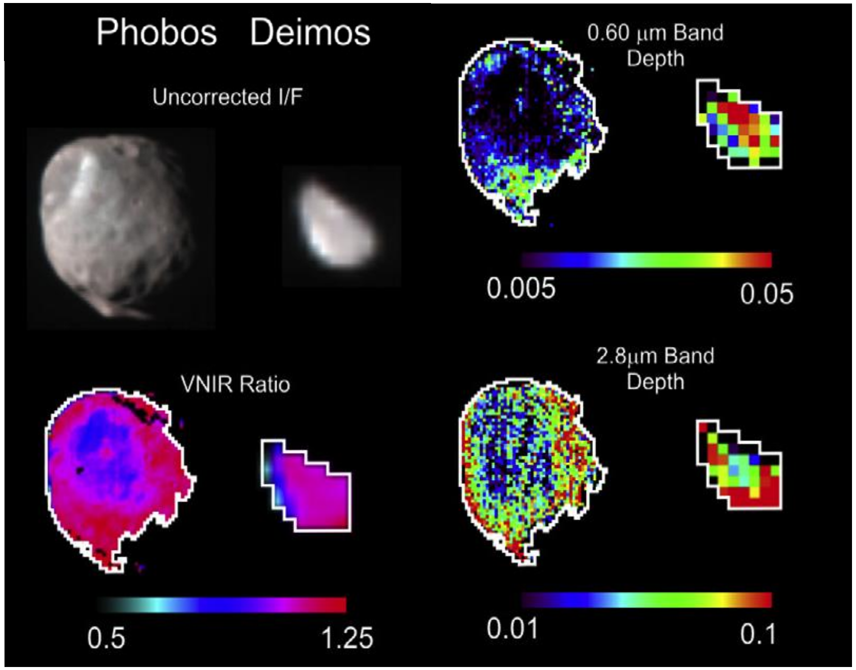
size: Phobos: 27x22x18 km Deimos: 15x12x11 km

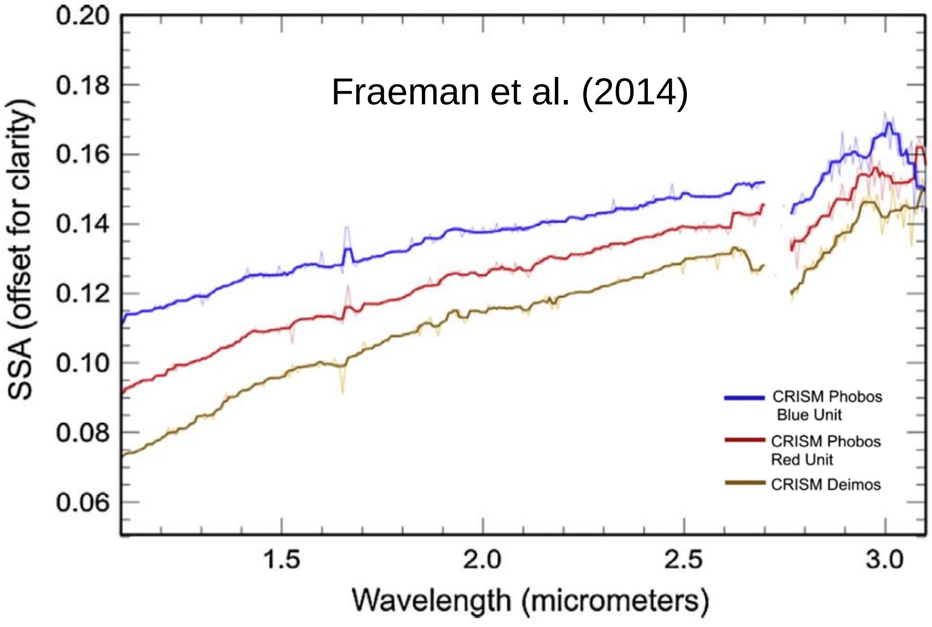
Density Phobos=1.87 g/cm^3; Deimos=1.47 g/cm^3 ➔ high porosity or lighter material inside

Mars satellites spectral features

- CRISM's detection of OH (2.7-2.8 micron) on Phobos and Deimos
- Redder unit has 0.65-µm and 2.8-µm absorptions suggesting Fe and OH in phyllosilicate
- Bluer unit has weak 2.8-µm OH absorption, otherwise bland





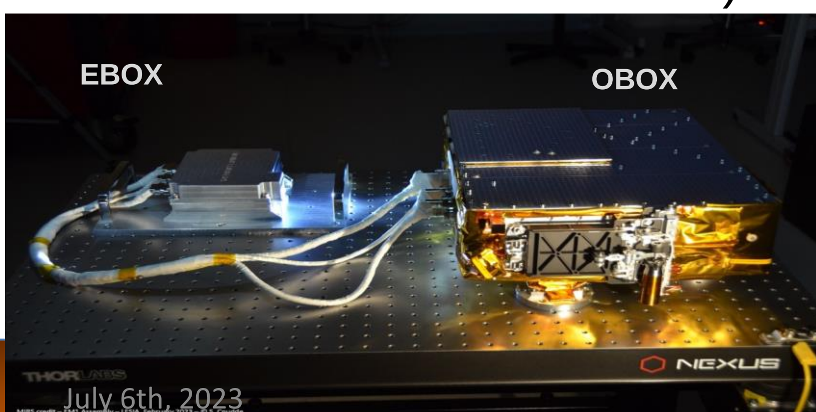


MIRS (MMX InfraRed Imaging Spectrometer)

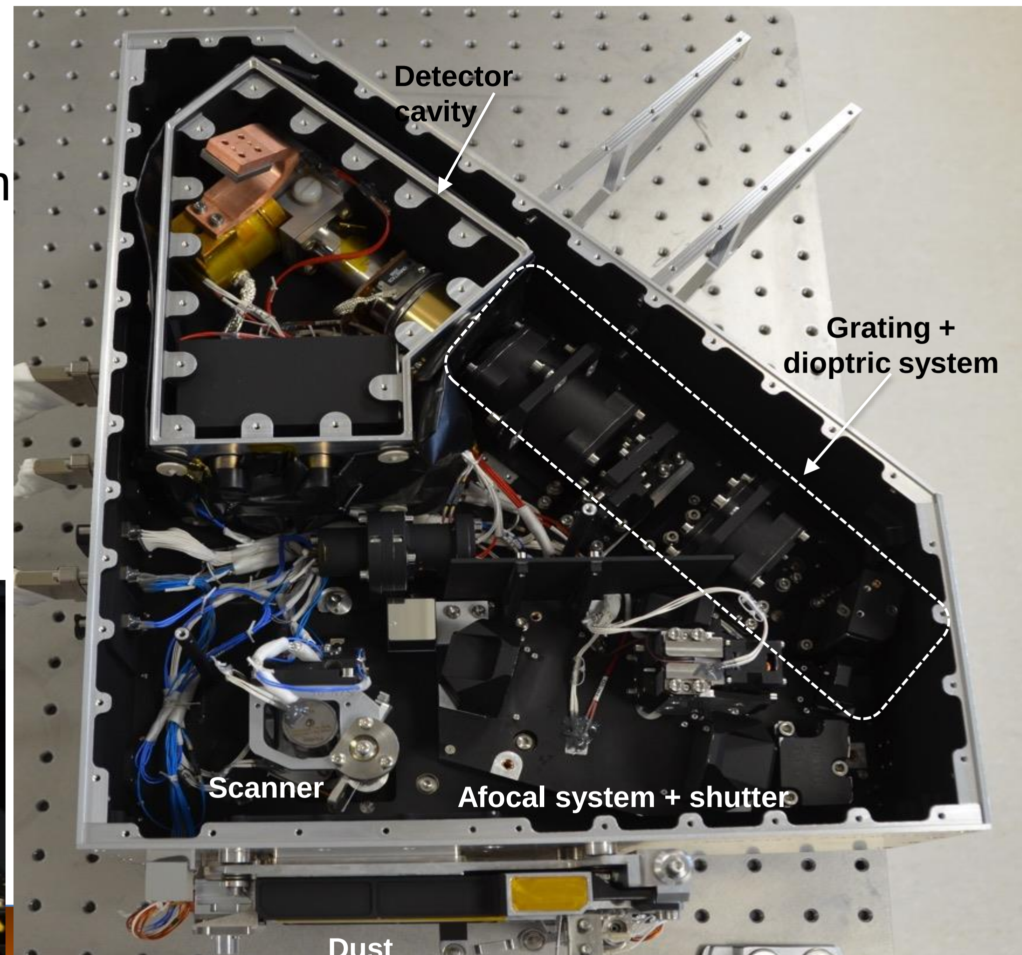
MIRS is provided by CNES and built at LESIA-Paris Observatory in collaboration with four other French laboratories (LAB, LATMOS, LAM, IRAP-OMP), and in close collaboration with JAXA and MELCO

Caracteristics

- Spectral range: 0.9 – 3.6µm
- Spectral resolution: < 24 nm
- Spectral sampling: 11 (±10%) nm
- IFOV: 0.35 mrad
- FOV: ±1.65°
- SNR: ≥ 100 in 2.7-3.2 µm
  (in less than 2 sec integration, for Phobos observed at α < 30 º)

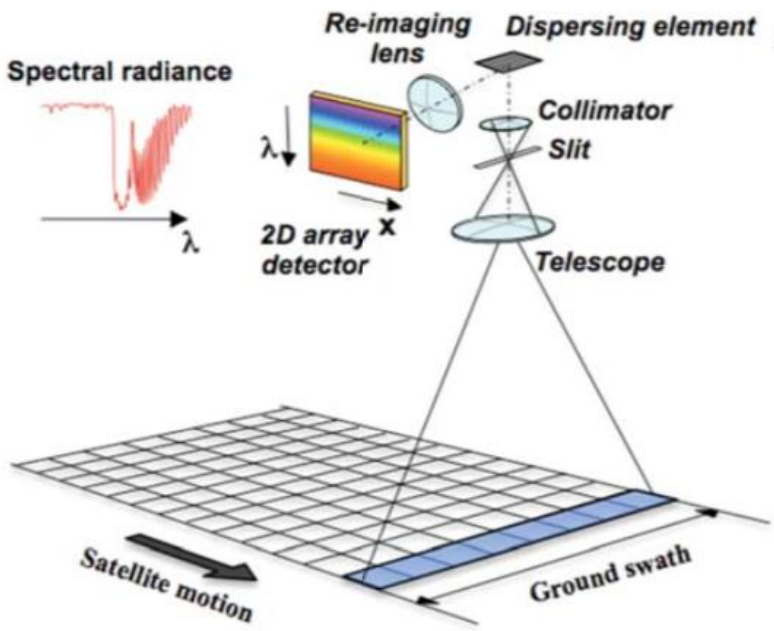


OBOX top view (without radiators)

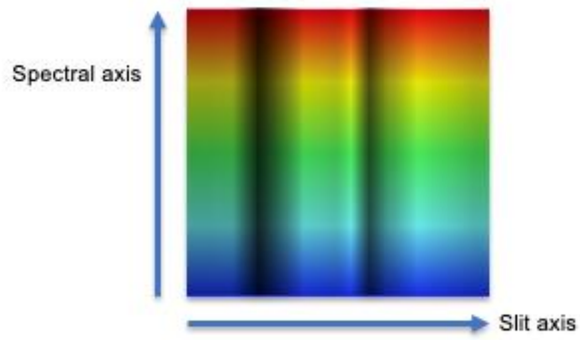


MIRS: a pushbroom spectrometer

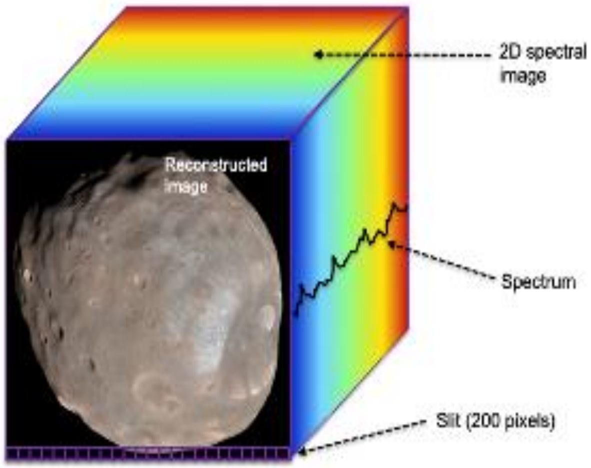
Pushbroom spectrometer principles:



MIRS Science TM: (x, λ) images



(x, y, λ) cubes (on-ground processing)



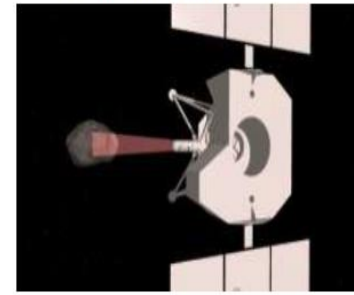
- Several raw images can be summed on-board to increase the SNR
- Background images are subtracted to science or calibration images on-board

- Downloaded TM: (x, λ) images (science, calibration, background) and HKs
- (x, y, λ) cubes reconstruction is performed on-ground

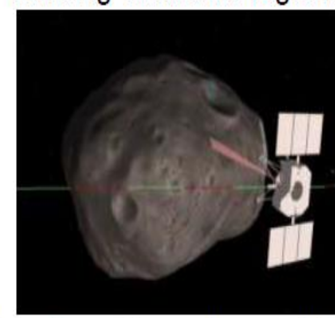
Phobos observations

MMX Trajectory	Objective	Targets
QSO-H (Phobos altitude: 90-190 km)	Global composition	Global mapping (priority on latitudes within +/-45°) **Res: 31.5-66.5m/px**
QSO-M (Altitude: 37-84 km)	Global composition & Landing Sites	1° 50 Landing Sites 2° Global mapping (**Res: 12.9-29.4m/px**)
QSO-LA (20-46 km)	Landing Site candidates fine characterization	20 Landing site candidates (**Res: 7-16 m/px**)
QSO-LC (6.6-16 km)	Landing Site candidates fine characterization and Thermal Inertia for Landing Sites	10 (or less) Landing Sites **16km → Res: 5.6m/px** **6.6km → 2.3m/px**
QSO-M3D (37-101 km)	Global composition and Thermal inertia determination	High/Low latitudes mapping (above/below 30°)
Vertical Descent Phase	Landing site characterization	Altitude from 2km to 400m TBC **400m → 14cm/px**

QSO-H & M



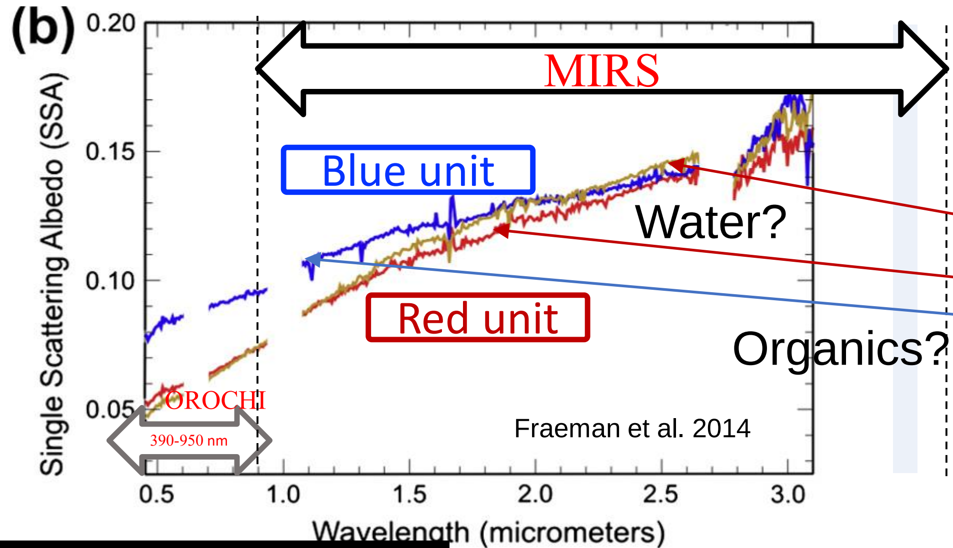
Landing candidate regions

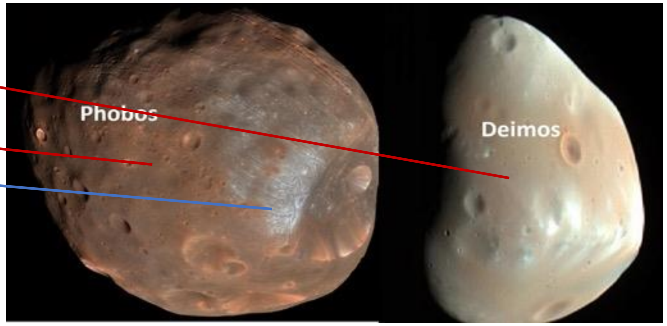


Landing sites: descent & ascent

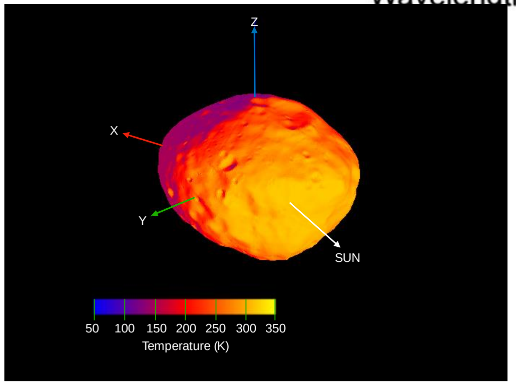
MIRS: Phobos Composition and Thermal Inertia

MIRS is expected to spectroscopically measure water (ice) (absorption band at 3.0-3.2 μm), hydrous silicate minerals (2.7-2.8 μm), measure organic matter (3.3-3.5 μm) and/or anhydrous silicate minerals (1.0 μm),at a spatial resolution of 20 m (QSO-M)

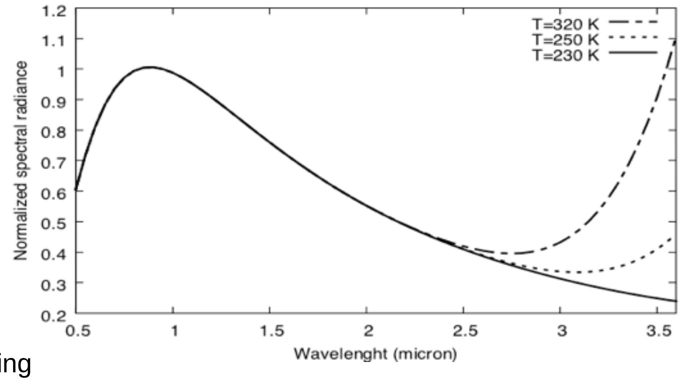




Mars Reconnaissance Orbiter (MRO)(NASA/JPL/Arizona Univ.)



Preliminary temperature calculation on Phobos using the Gaskell shape mode: 98000 facets (Gaskell, 2011)

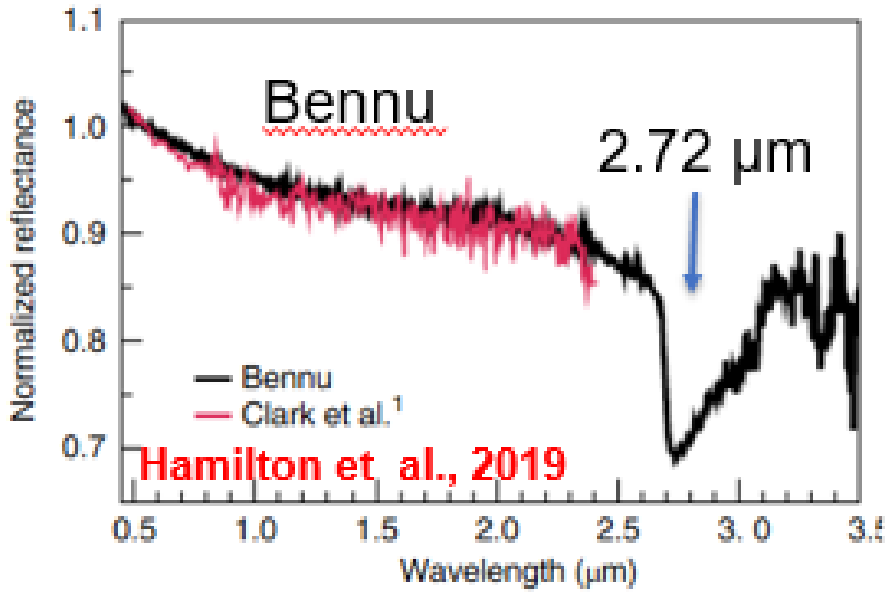


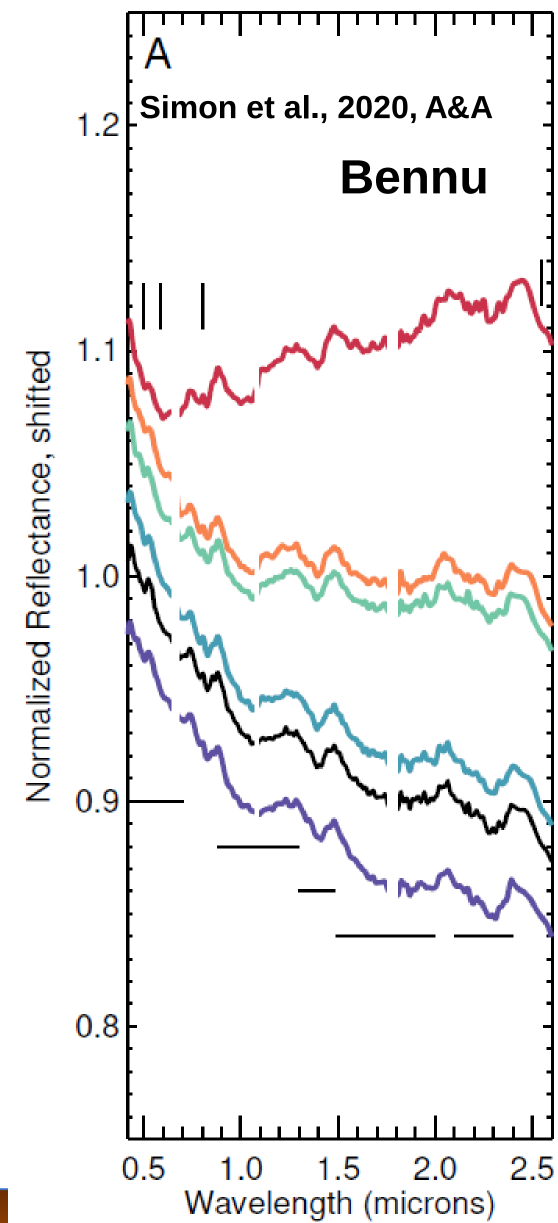
Thermal tail to assess:

- Surface Temperature
- Spatial Temperature & temporal variation
- Thermal Inertia

Diagnostic spectral features

In situ observations may reveal faint absorption bands undetected from ground. For example the Near Earth Asteroid Bennu has several bands with depth of a few percent (1.05, 1.4, 1.8, 2.3 microns, beside the deeper 2.7 micron band), as observed by OSIRIS-REX mission, requiring S/N ratio > 100 to be detected and characterized, that is largely achieved by MIRS in the 1-2.7 micron range)





Diagnostic spectral features

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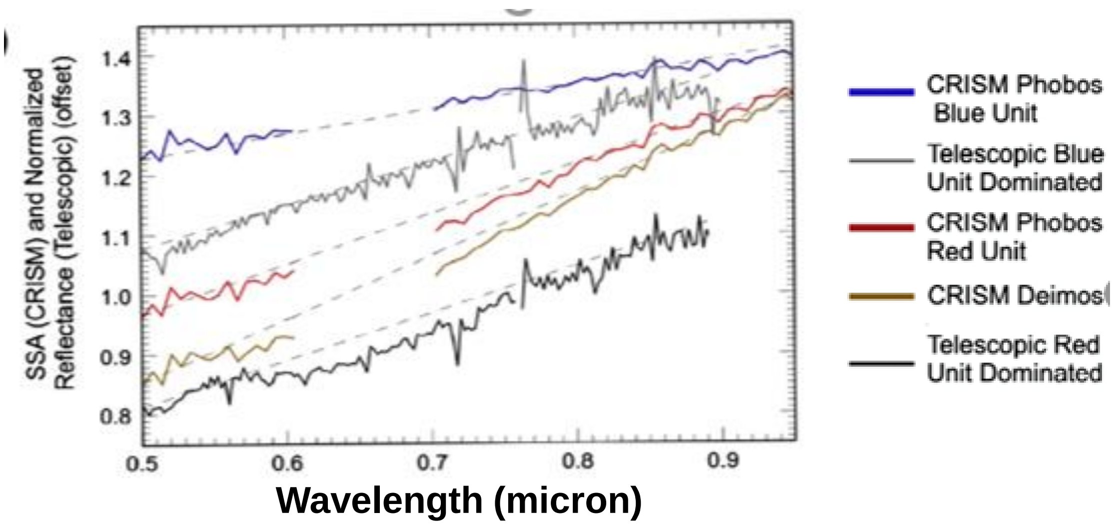
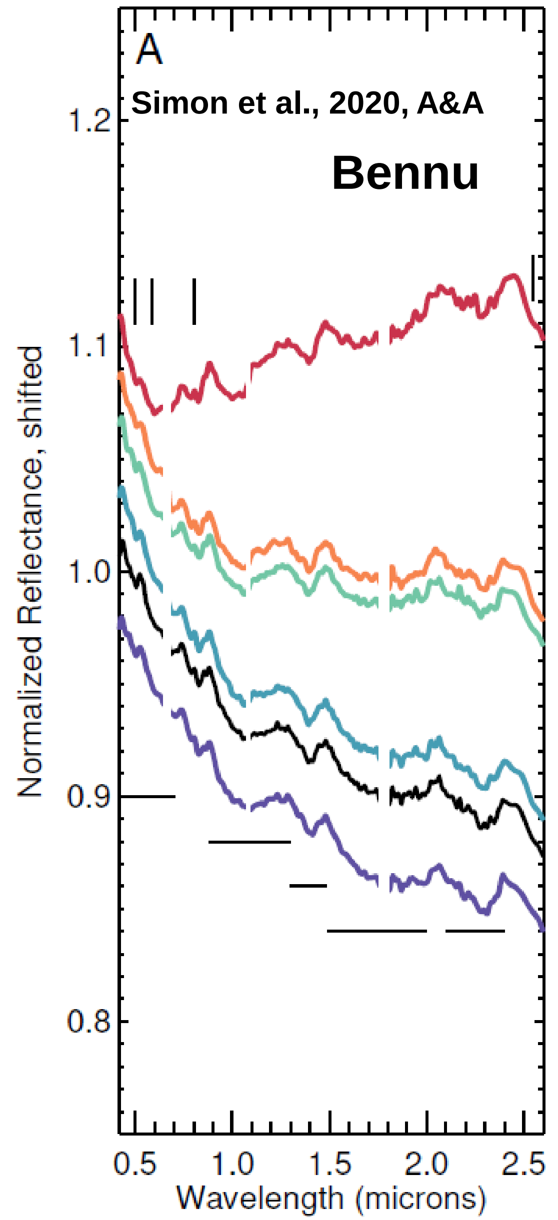
Phobos has a ~0.65-µm band attributed to saponite group phyllosilicates (Cloutis et al. 2011); However, it is also consistent with space weathering effects and mixture of µm and sub-µm iron grains.

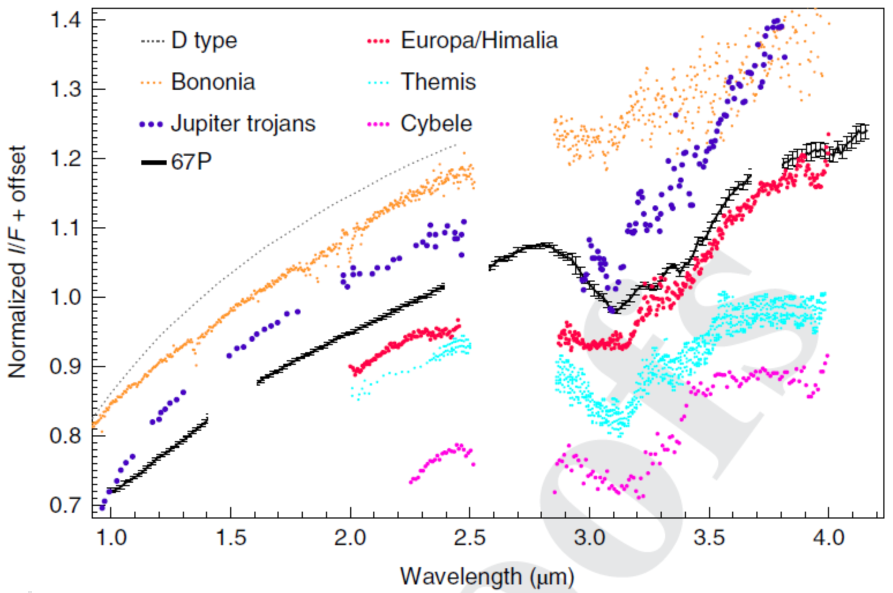
If due to saponite, MIRS may detect faint 1.4&2.3 micron bands

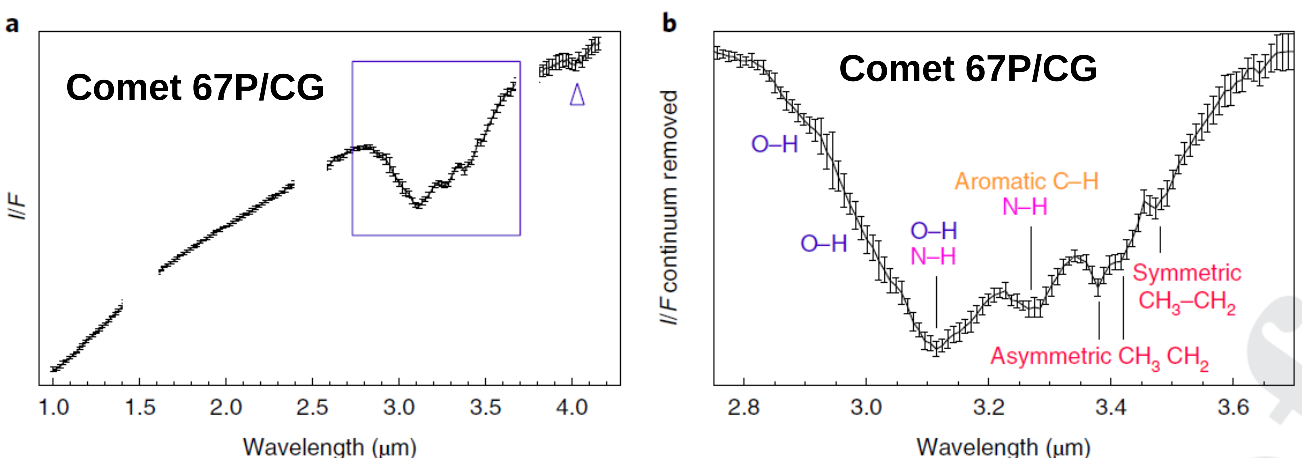




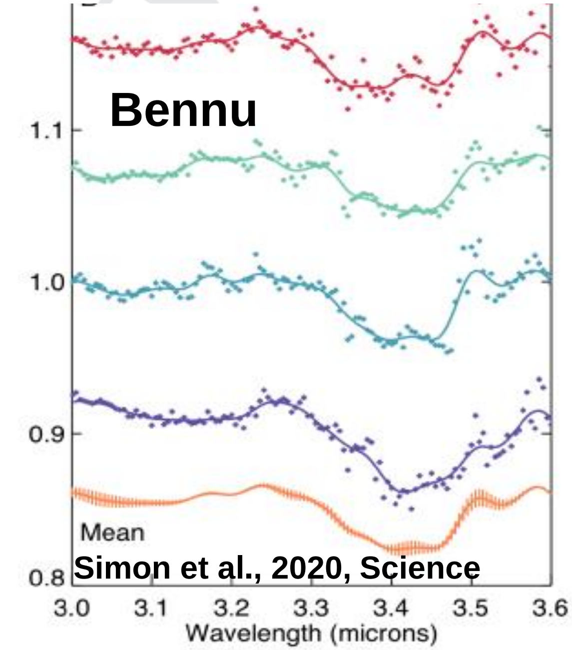
Organics

- Organics have been detected on the surface of many asteroids, and comets
- For Bennu, OSIRIS-REX mission detected 3% absorption features (Simon et al. 2020). A SNR > 40 will permit the identification of similar features on Phobos
- Usually, we can expect absorption features in the 3.2-3.4 micron region if Phobos and Deimos are captured asteroids



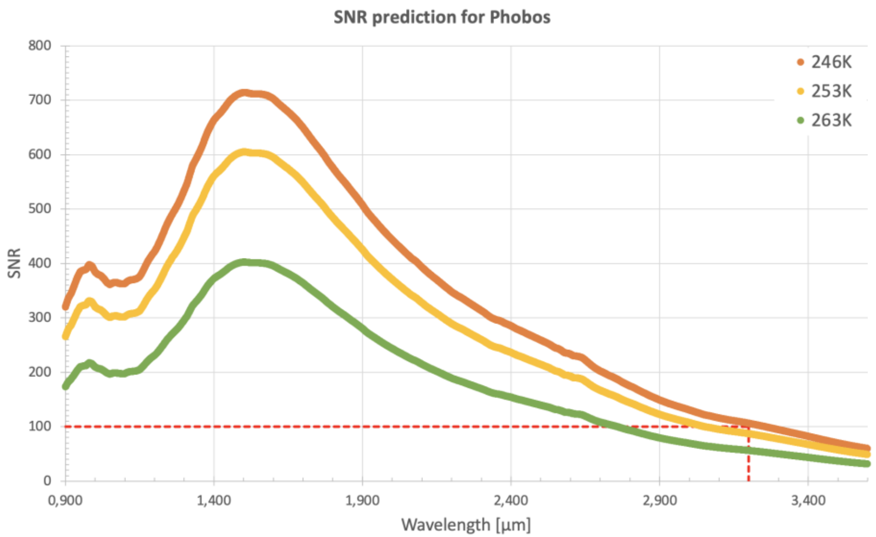


Raponi et al., 2020, Nat. Astronomy



Simon et al., 2020, Science

Signal to Noise Ratio: Phobos



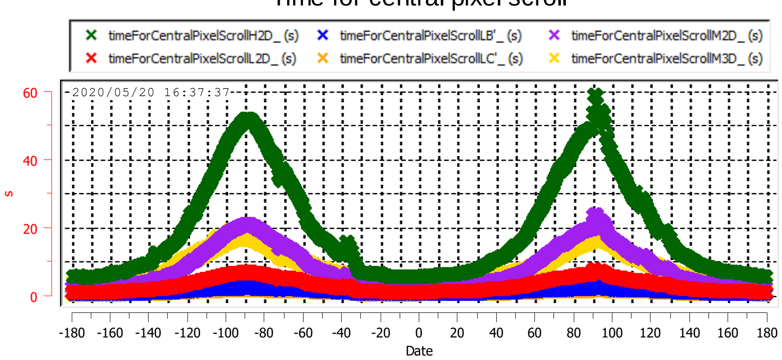
Phobos QSO-M is the reference case for SNR, with minimum pixel scroll of 2s and phase angle of 30°

SNR requirement (≥ 100 @3.2µm) is not met in 2 s integration time when the spectrometer temp is ≥ 250K. Two ways for SNR improvement:

1. Increasing the integration time (max accumulations = 16)

Parameter	T spectro 246K	T spectro 253K	T spectro 263K
Integration time for 1 frame	215 ms	151 ms	91 ms
Number of accumulations	9	13	16
Total integration time	1.94 s	1.96 s	1.46 s
SNR @3.2 µm in less than 2 s	106	87	56
SNR @3.2 µm in less than 3 s	133	97	56

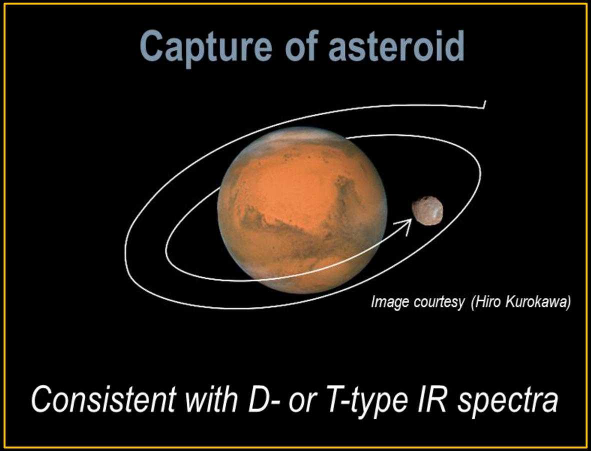
85% of the QSO-M orbit has a pixel scroll ≥ 3 s



2. Limiting the phase angle (Ops constraints):

Parameter	Phase ang. 30°	Phase ang. 20°	Phase ang. 0°
Integration time for 1 frame	215 ms	208 ms	142 ms
Number of accumulations	9	9	14
Total integration time	1.94 s	1.87 s	1.99 s
SNR @3.2 µm in less than 2 s	106	142	342

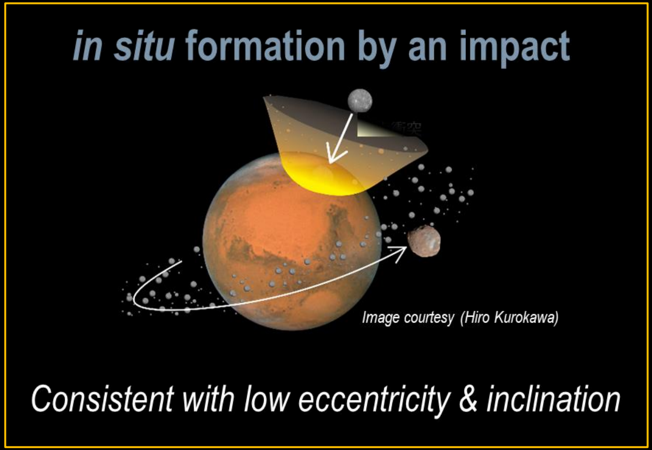
How MIRS may constraint the satellites origin



-the satellites show a composition similar to carbonaceous chondrites

-presence of hydrated minerals→ Hydrated CC

-presence of organics



-presence of thermally evolved minerals

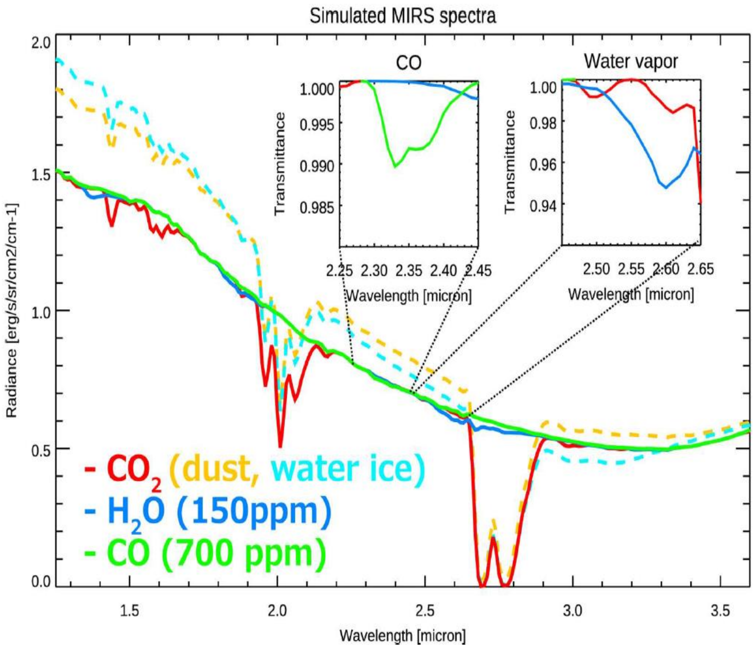
-no OH absorption & organic at all

- mixing of chondritic composition and martian composition

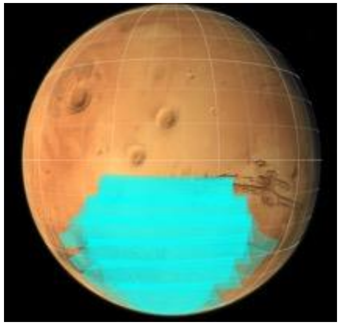
Martian atmosphere

MR2.3.1 To **constrain transport processes for dust and water near the Martian surface,** continuous observations of the mid- to low-latitude distributions of dust storms, ice clouds, and water vapor in the Martian atmosphere.

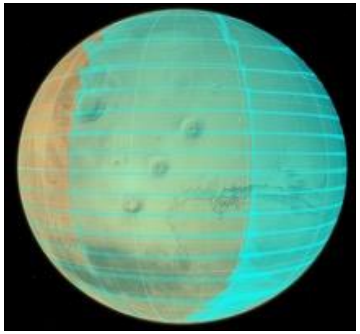
MMX is quasi-geostationary satellite:
unique opportunity for water and dust cycles



Mars Tracking strategy allows to observe several times a zone of interest (temporal resolution less than 1hr for selected areas)



Monitoring mode for complete coverage (alt. = 6000 km →pixel footprint ~2.1 km).
MIRS will cover the global day light Mars hemisphere in a few days.



Conclusions

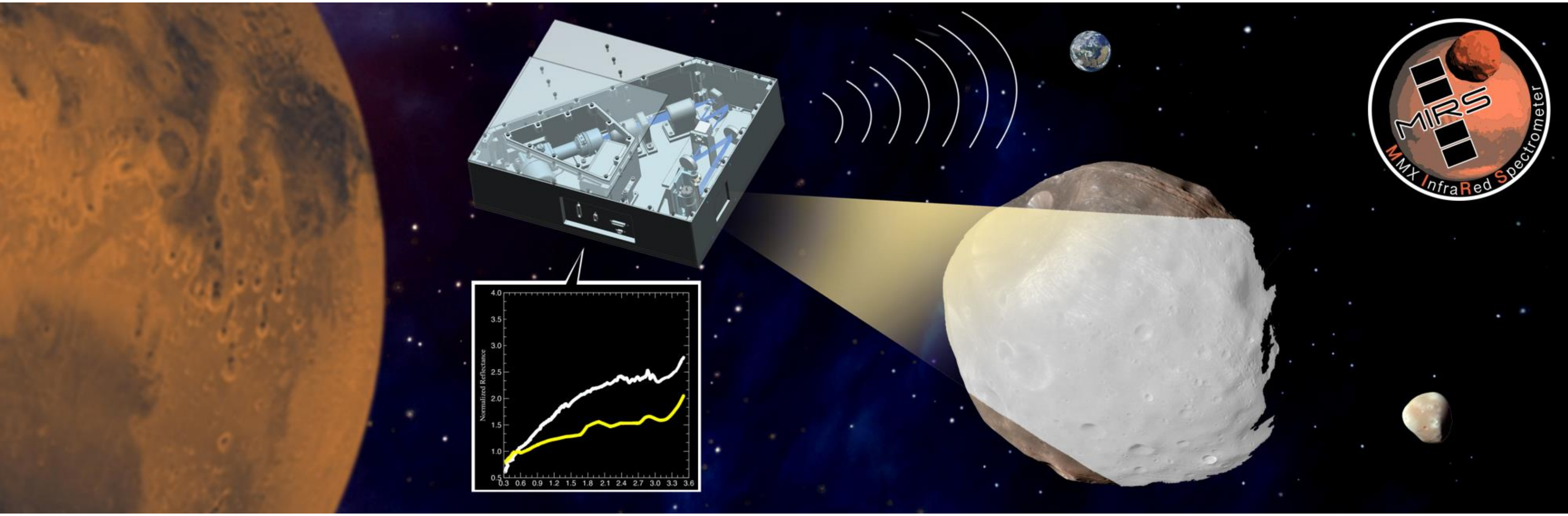
- The high SNR, the wide spectral coverage, and the unprecedented spatial resolution achieved by MIRS will permit to fully characterize the composition and mineralogy of Phobos and Deimos, in particular to detect anhydrous silicates, hydrated silicates, water ice, and organic matter, if present → **clarify the origin of the Martian moons**

- MIRS will permit to investigate the local compositional heterogeneity associated with the different geomorphological features across Phobos surface

- MIRS will support the sampling site selection

- MIRS will also study Mars atmosphere, in particular the spatial and temporal changes such as clouds, dust and water vapor.

Thanks for the your attention



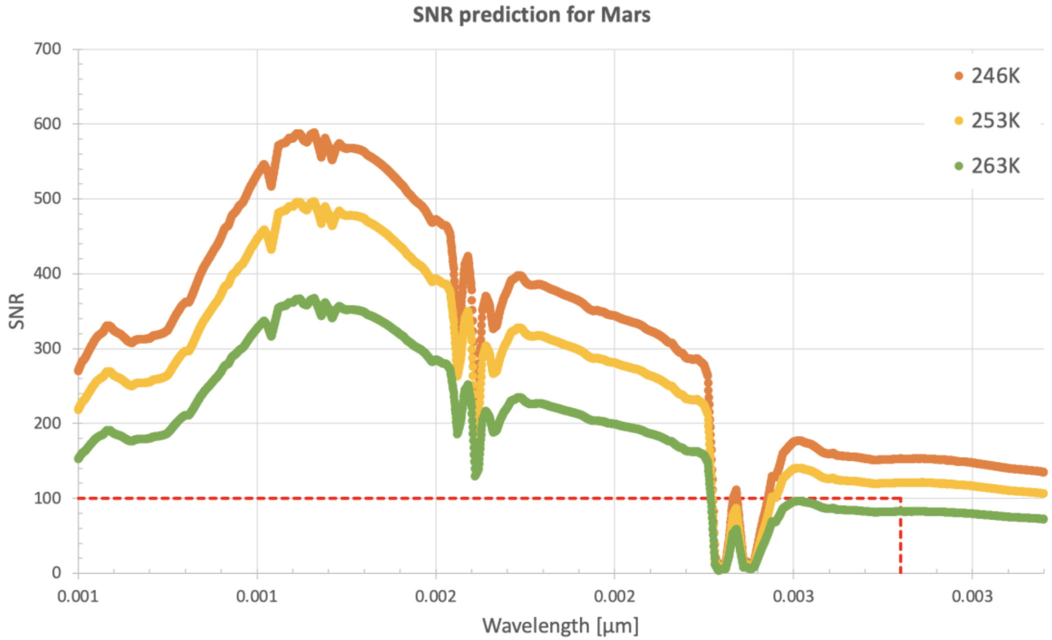
MIRS major scientific objectifs

1. Clarify the origins of the Martian moons and constrain processes for planetary formation and material transport in the region connecting the inner and outer solar system

2. Clarify the driving mechanism of the transition of the Mars-moons system and add new knowledge to the evolution history of Mars.

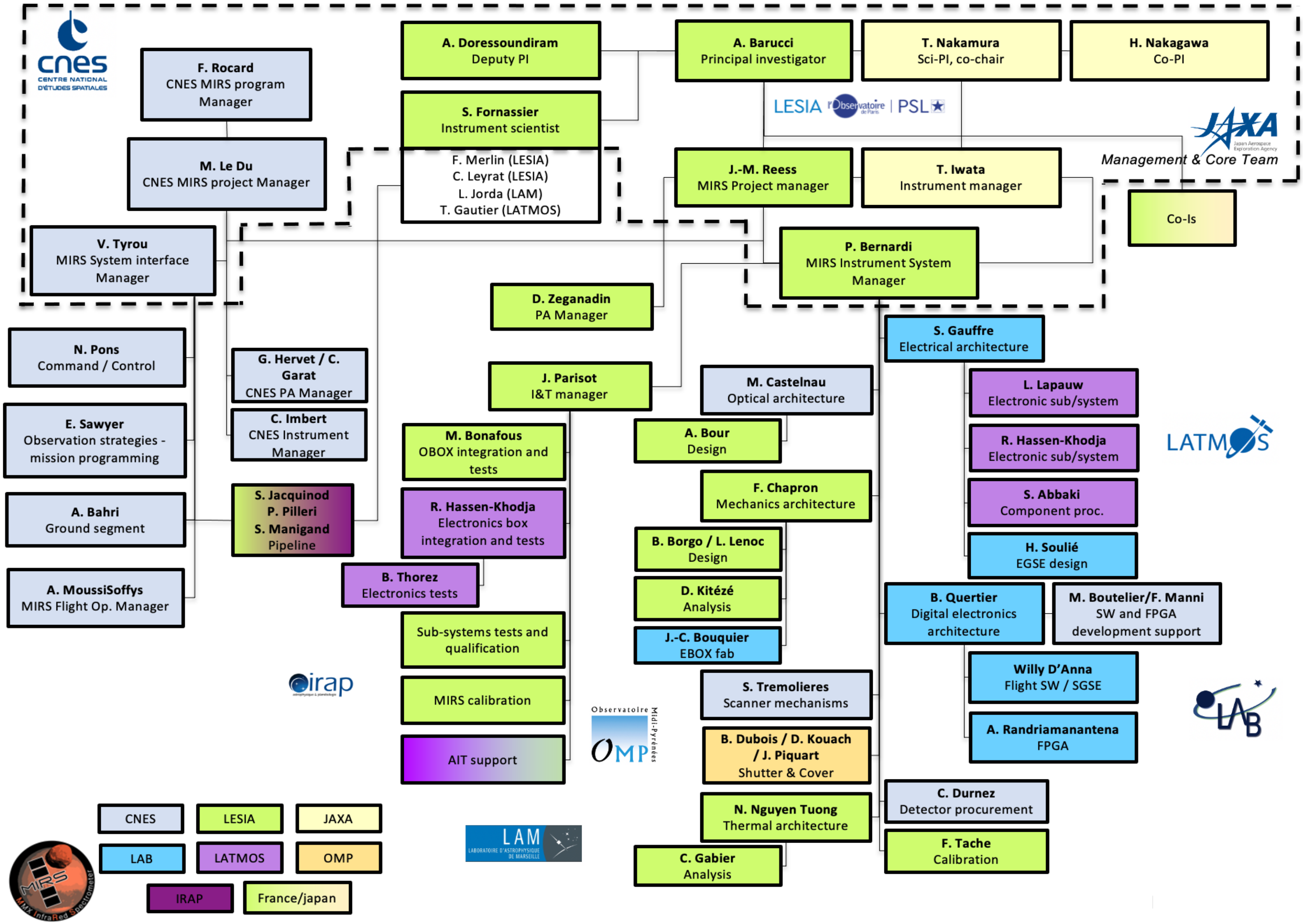
Signal to Noise Ratio: Mars

- SNR performance is met more easily for Mars observations ("average" irradiance):



Parameter	T spectro 246K	T spectro 253K	T spectro 263K
Integration time for 1 frame	79 ms	67 ms	49 ms
Number of accumulations	1	1	1
SNR @3.2 µm in less than 2 s	153	121	82

MIRS Organigram



MIRS Model philosophy

#	Models	Description	Delivery to JAXA	Goals
1	MIRS-Sim (+ MDHS)	Simulator for cmd-ctrl IF check w/ MDP	**YES**, August 2021 + additional tests in Fr in July 2022	Validation of com. w/ MDP
2	STM2	Structural and Thermal model	**YES**, December 2020	S/C TVAC & acoustic tests
3	STM1	Structural and Thermal model	NO	Qualification of the mechanical structure and TVAC. Test vehicle for equipment qual if needed
4	EM2	"EMIC" (Electrical and Mechanical I/F Check)	**YES**, July 2022	Validation of mechanical, electrical and com IF. Auto-compatibility at S/C level.
5	EM1	Engineering Model. Fully functional. Best effort for performance.	NO	Fully functional model. Validation of test procedures (integration, optical alignment, functional, performance). Validation of FSW. Performance assessment (at cold). E2E System validation. Future ground model.
6	PFM	Proto-flight model	**YES**, Sept 2023	Science!
7	FS	Flight spare (not assembled)	NO	Spare kit

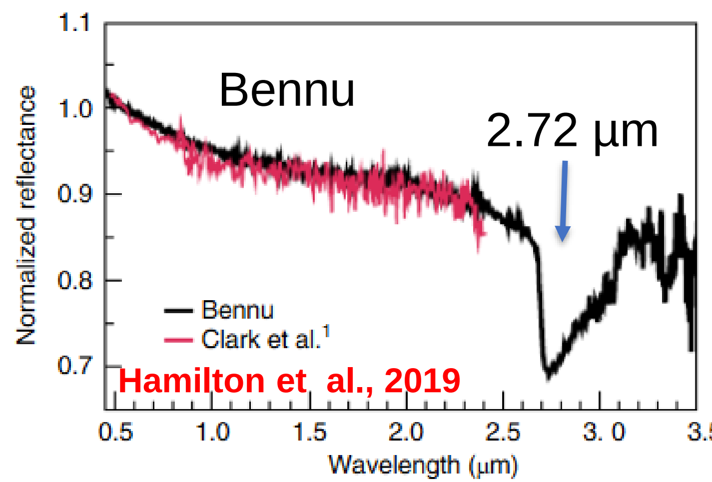
Diagnostic spectral features

- MIRS has a large wavelength coverage (0.9-3.6 μm) permitting the detailed determination of the mineralogical composition of the (mineralogy

Phase	Absorption band position (μm)	Cause
Serpentines	~0.90–0.94 ~1.1–1.2 ~1.4 ~1.9 ~2.3	Octahedral Fe^{2+} Octahedral Fe^{2} OH OH/H_2O Mg–OH
Saponites	~0.9 ~1.1–1.2 ~1.4 ~2.3	Octahedral Fe^{2+} Octahedral Fe^{2+} OH Mg-OH
Ferrihydrite	~1.4 ~1.9	OH^{+} OH/H_2O
Magnetite	~1–1.3	Fe^{3+}spin-forbidden Octahedral Fe^{2+}
Hexahydrite/epsomite	~1.45 ~1.95 ~2.5	H_2O H_2O H_2O
Carbonates	~2.3 ⩾2.5	C–O C–O

Major absorption bands positions observed in laboratory on CI constituent minerals (Cloutis et al., 2011)

Wavelength (μm)	Assignment
1.21	2nd overtone of CH_3 asymmetric stretch
1.39-1.41	1st overtone of OH stretch
1.69-1.76	1st overtones and comb. of CH_2 and CH_3 stretching modes
2.15-2.17	combination of aromatic C-H stretch and C=C stretch
2.27	combinations of CH_2 asymmetric stretch and symmetric bend
2.31	combinations of CH_3 asymmetric stretch and symmetric bend
2.35	combinations of CH_3 asymmetric stretch and symmetric bend
2.46	CH_2
2.94-3.12	N-H and NH_2 group (stretch)
3.27-3.29	aromatic CH stretch or Fermi resonance
3.38-3.39	aliphatic CH_3 asymmetric stretch
3.41-3.42	aliphatic CH_2 asymmetric stretch
3.48-3.50	aliphatic CH_3 symmetric stretch
3.50	aliphatic CH_2 symmetric stretch



Deimos

M01.3.1. Clarify the surface distribution of materials composing Deimos through spectroscopy with the spatial resolution necessary for grasping its geological structures and compare this with Phobos.

MIRS is expected to spectroscopically map at a spatial resolution of 100 m major absorption bands as observed in Phobos, as water (ice) and hydrous silicate minerals

We plan to observe Deimos during the approach from ~ 300 km to TBD. Deimos will be covered within the MIRS FOV, with a pixel size decreasing from 105 m down to TBD m.

MIRS EM1: TVAC test setup

TVAC facility at LESIA (Paris-Meudon Observatory)

Optical bench in front of the TVAC Chamber. Used for optical performance measurements.