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Near-Infrared Hyperspectral Imager NIRS4/MacrOmega on MMX

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Abstract (1/2)

The Martian Moons Exploration (MMX) is a probe which will be launched by the Japanese launch vehicle H-III and will navigate the quasi satellite orbit of Phobos, and will make a fly-by of Deimos. **NIRS4/MacrOmega** is an imaging spectrometer in the wavelength range of **0.9 to 3.6 µm** which is one of the candidate instruments to be installed on the MMX spacecraft. It is based on MicrOmega on the ExoMars Rover and Hayabusa2 MASCOT and modified as a hyper-spectral imager with spectroscopic function provided by an **Acousto-Optic Tunable Filter (AOTF)**.

MMX aims to elucidate the evolution of our solar system by investigating the migration process of primitive materials in the early stage. NIRS4/MacrOmega will observe hydroxide or hydrated mineral absorptions on **Phobos and Deimos** in the wavelength of 2.7-3.2 µm. By analyzing the shape of the spectra, we will distinguish between water in hydrous silicate minerals, water molecules, and water ice particles. NIRS4/MacrOmega will also try to detect the absorption by organic matter in the wavelength range of 3.3-3.5 micrometers. These results will support efforts to answer the question of the origin of the Martian satellites, and identify whether they are satellites formed by a giant impact or asteroids captured by Mars.

Abstract (2/2)

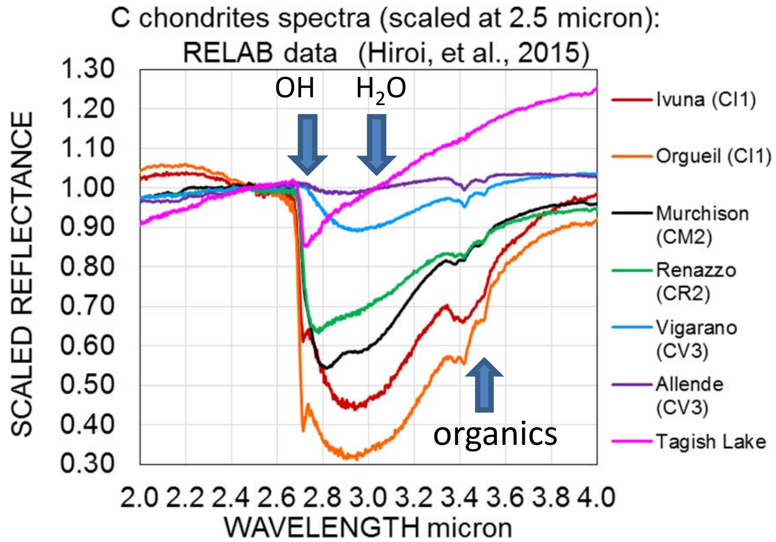
NIRS4/MacrOmega will observe **Phobos** to survey the **sampling site** before sampling, to investigate the sampling site precisely at the touch-down mode, and to make global mapping. Global mapping of Phobos to select prior areas and landing sites will be performed on the quasi satellite orbit at 100 to 200 km in altitude. Precise mapping for candidate landing sites will follow at about 20 km in altitude. We will also perform high-resolution observation for selected areas at the orbit lower than 10 km, and precise observations of blue and red regions at the Mars-Phobos Lagrangian points 1 and 2. In the touch down phase, we will observe the sampling site at full wavelength at altitudes from 20 km to 1 m. Observations for **Deimos** will be basically executed from the fly-by orbit, and they are examined to be made at the near circular orbit.

NIRS4/MacrOmega will also observe the **Atmosphere on Mars** from the orbit beside Phobos, which can provide a global imaging toward Mars with high temporal resolution. We will derive column density of water vaper and ice cloud by retrieval methods. We will also obtain surface pressure of CO_2 and column densities of CO, *etc*. to elucidate the water cycle in the Martian environment.

Target wavelength

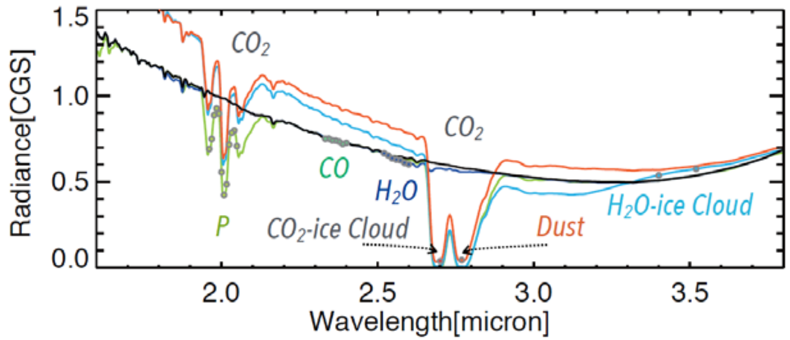
Phobos and Deimos

Materials on Phobos / Deimos	λ (μm) [resolution]
Hydroxide minerals	2.7 - 2.8 [0.02]
Hydrated minerals	3.0 - 3.2 [0.02]
Organics (linear chain structure)	3.3 - 3.5 [0.02]
Reflective Cont.	0.9 - 3.6 [0.02]
Radiation (temperature)	3.2 - 3.6 [0.02]



Mars atmosphere

Atmosphere on Mars	λ (μm) [resolution]
H_2O	2.50 - 2.65 [0.003]
Pressure (CO_2 absorption)	1.90 - 2.20 [0.003]
Dust / aerosol amount (CO_2 abs)	2.65 - 2.90 [0.003]
Dust / aerosol: size & n (cont.)	0.90 - 3.60 [0.02]
[Others] O_2 (1.27μm), CO (2.3μm), H_2O-ice (~3.5μm)	



⇒ **0.9 - 3.6 μm**

Wavelength Selection for Mars

In order to achieve spatial & temporal resolution, we need to restrict the scanned wavelength channels due to FOV-drift.

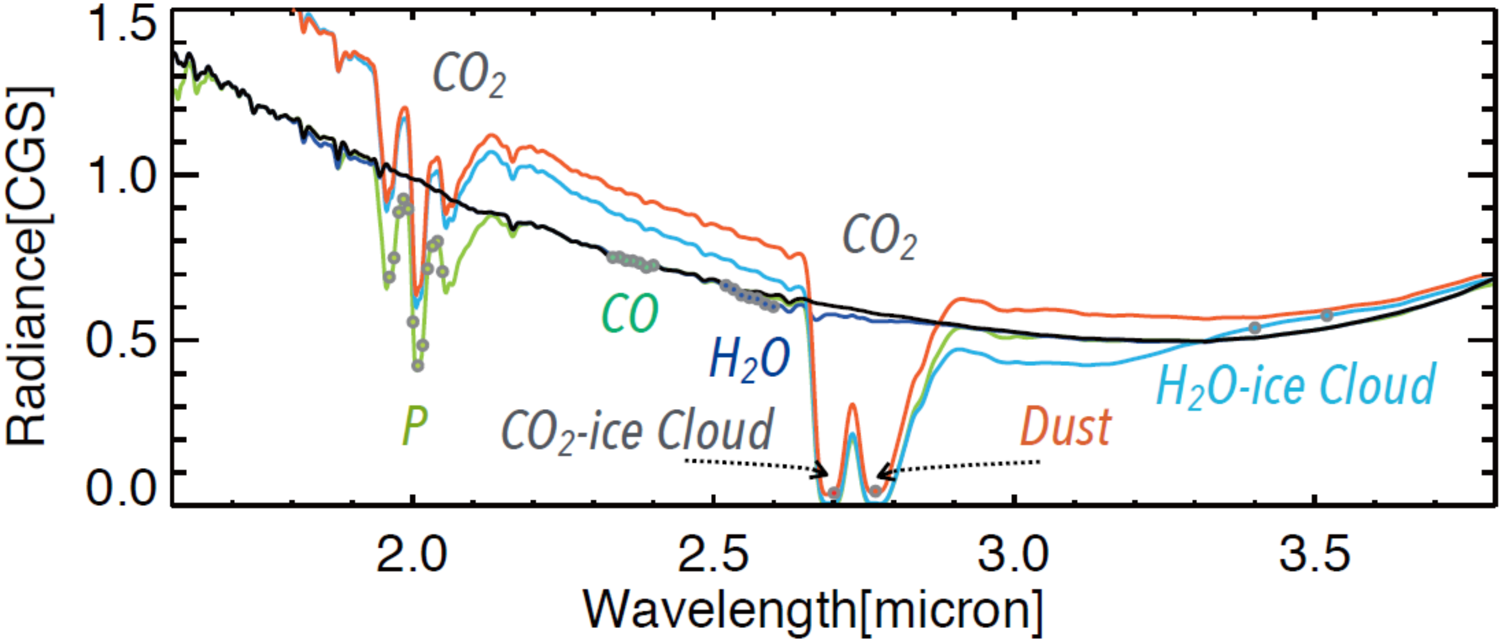


Fig. Synthetic spectrum of Martian atmosphere between 1.6 and 3.8 micron (20cm^{-1} res., 2cm^{-1} sampling).

Tab. Selected wavelength channel of atmospheric compounds of interest.

Molecule	H_2O	H_2O Cloud
λ(μm)	2.5-2.65	3.3-3.6
N. Channel	8	2
Precision	1 pr-μm	Δτ=0.1

Strategy for Mars mapping

Scanning using 1-axis scanner mirror and S/C maneuver motion is necessary for global mapping. In order to achieve spatial and temporal resolution, 4pix-binning to be **9.6km**/bin.

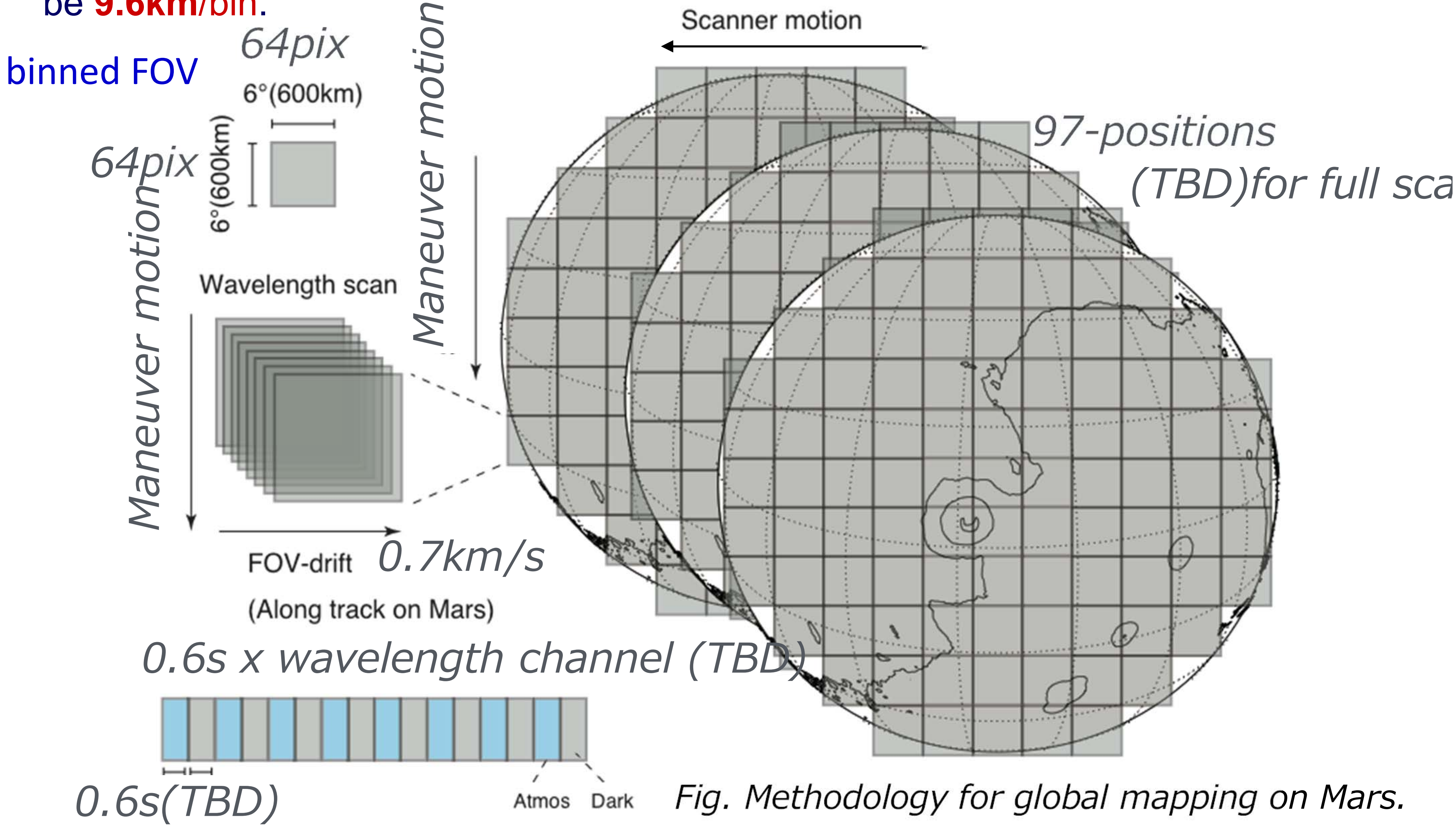
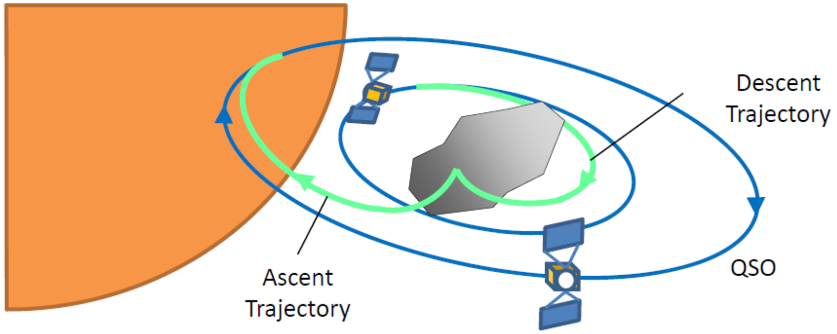


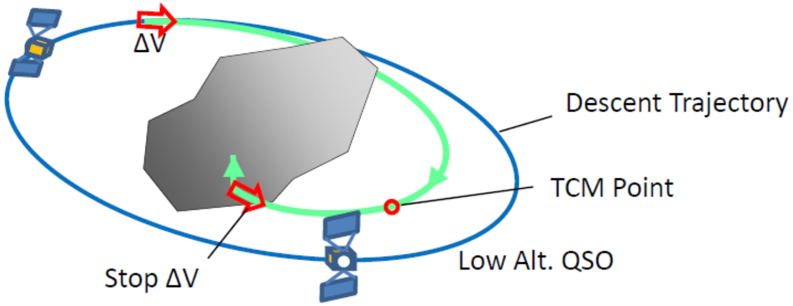
Fig. Methodology for global mapping on Mars.

Operation orbit and subjects

target	orbit	subjects	S/N
Phobos	**100 km**	Global mapping of Phobos to select priority areas and landing sites	>100
	20 km	Precise mapping for candidate landing sites, Precise mapping for selected areas	>300
	Low (TBD km)	High-resolution observation for selected areas	>100
	L1, L2-point	Precise observations toward blue (L1) & red (L2) region, calibration for phase angle	>100
	20km → 1m → 20km *	Precise observations toward sampling sites *) full wavelength at 40 → 10m	>100
Deimos	Fly-by	Semi-global mapping of Deimos	>100
Mars atmosphere	Phobos QSO	Global mapping and monitoring to select proper materials and areas	>300
		Precise observations toward selected areas, such as Tharsis, Arbia Terra, etc.	>300

Tentative Profile for descending sequence





Phase	ΔT	altitude	λ
1) Initial ΔV for Descent	1min	20km	
2) Ballistic Trajectory-1	60min	20km→10km	Selected
3) TCM (Trim Correction Mnv.)	1min	10km(TBD)	
4) Ballistic Trajectory-2	30min	10km→1km	Selected
5) Stop-ΔV	1min	1km	
6) Lateral Position/Velocity Correction	10 ~ 60min	1km	Selected
7) Vertical Descent	20min	**1km→50m**	**Full**
8) TM Separation	1min	50m→40m	
9) 6 DOF (degree of freedom) Control	**20min**	**40m→10m**	**Full**
10) Hovering	5min	10m	Selected
11) Free Fall	5min	10m→1m	Selected
12) Touch Down	**TBD**	**1m**	**Full x2**

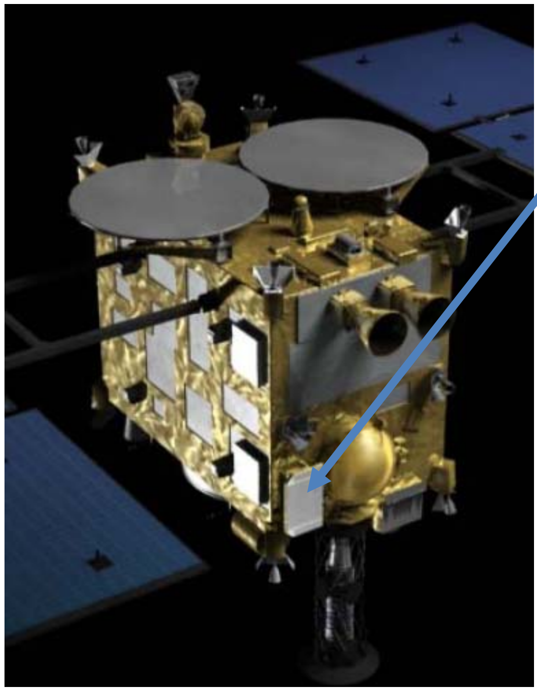
Imaging methods of VIS/NIR spectrometers

point/slit spectrometer (1D/2D-sensor)

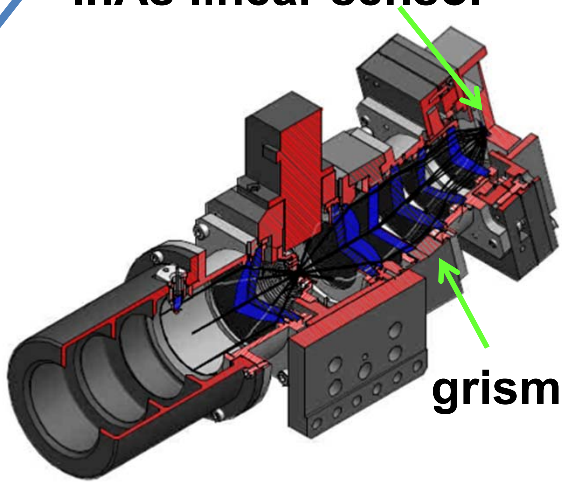
- scanning for 2D-space
- simultaneous for wavelength
- Grism, Grating, Prism, or LVF (Linear Variable Filter)

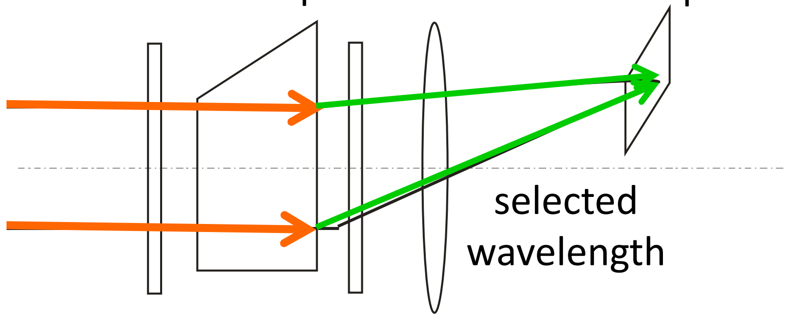
Hyperspectral Imaging

- simultaneous for 2D-space
- scanning for wavelength
- AOTF(Acousto-Optic Tunable Filter) or LCTF (Liquid Crystal Tunable Filter)



NIRS3 on hayabusa2
(1.8-3.2 μm)





Schematics of AOTF imager.

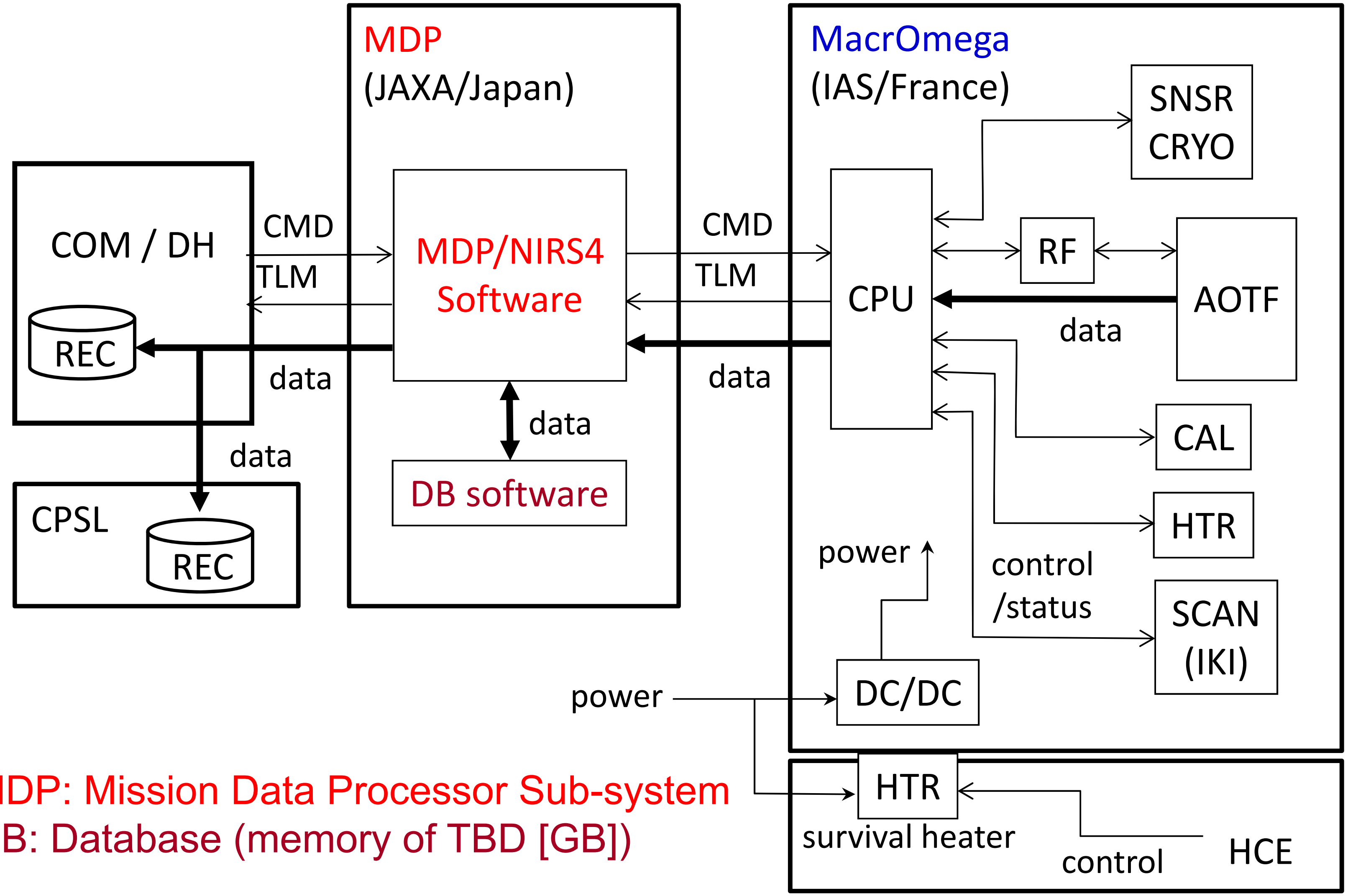
Comparison of MacrOmega to NIRS3

item	MacrOmega	NIRS3 (*)
Spacecraft	MMX	Hayabusa2
Spectroscopic methods	AOTF	grism
Sensor	2D HgCdTe sensor	1D InAs sensor
λ	0.9 - 3.6 µm	1.8 - 3.2 µm
FOV	6 deg (256 x 256 pix)	0.11 deg
Fno	6	-
Area , resolution (@20km alt.)	2.1 x 2.1 km, 8.2m/pix	40m/pix
Beam diameter	15 mm / (20 mm :op.) at AOTF	35 mmϕ aperture
Throughput	0.15	0.6-0.9
Exposure time for S/N=100 (†)	298 to 410 / 224 to 307 ms	~110 ms (@2.7µm)
Δλ	$\Delta\sigma$=20cm^{-1} ⇒ Δλ=2nm @1µm, Δλ=8nm @2µm, Δλ=24nm @3.5µm	Δλ=18nm

*) Iwata *et al.* (2017), *Space Sci. Rev.*, doi:10.1007/s11214-017-0341-0.

†) Values are depending on the wavelength characteristics. Values of AOTF are tentative.

A conceptual block diagram of NIRS4:MacrOmega



MDP: Mission Data Processor Sub-system
DB: Database (memory of TBD [GB])

Functional boundary and requirement for MDP and MacrOmega

MDP/NIRS4-softwase	MacrOmega/CPU
<control transmission> - To transmit CMD from COM to MacrOmega. - To transmit TLM from MacrOmega to COM. <data acquisition> - To store and transmit the data between MacrOmega, DE/REC, and COM. - To select data from MacrOmega by considering index and transmit to COM as real-time data during the special events. <data calculation> - To cut and restore the data-pixel designated by wavelength and by spatial region. - To execute binning by wavelength and by spatial region. - To make thumbnails by using spatially binned data. - To integrate the data obtained at the different time, which needs to consider the difference of attitudes. - To calculate the color ratio of amplitude between two data. - To select the data which satisfy designated conditions. - To compress data.	<control instruments> - To control CRYO. - To set the frequency and status of the AOTF. - To turn on/off CALIB. - To control HTR. - To slue the SCAN. <data acquisition> - To acquire the data with designated parameters. <data calculation> - To subtract dark signals from sky signals. - To calculate average, maximum, minimum, and variance values. - To execute the spatial binning. - To compress data.

Major requirements and optional cases

- Baseline:
  15mm-AOTF
  far-field optics
  1-D scan mirror
- Optional cases:
  20-mm AOTF
  near-field optics
  2-D scan mirror

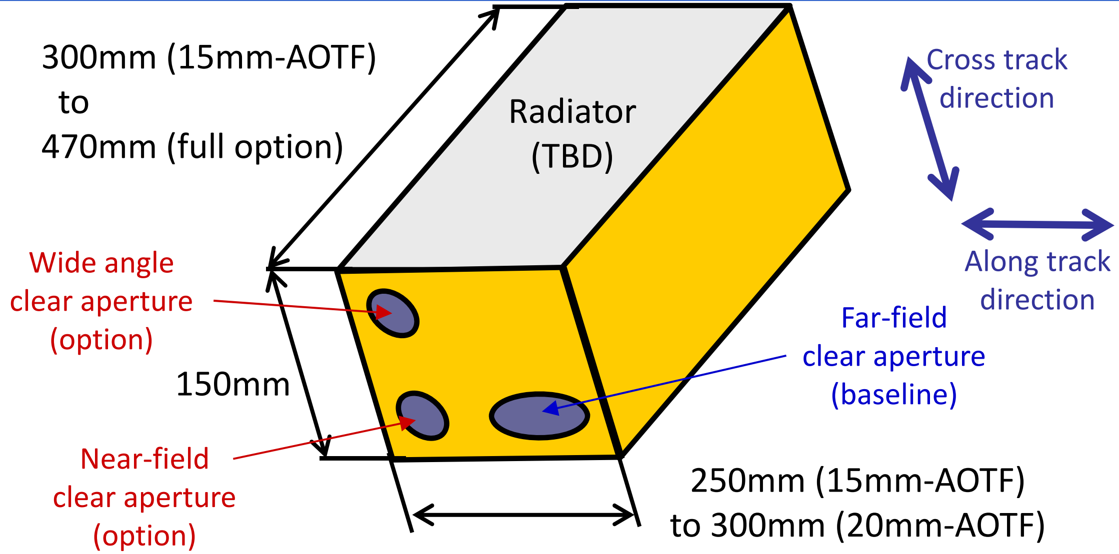


Table) NIRS4/MacrOmega mass

Component case	Mass [kg] (*)
nominal (15mm-AOTF)	5.00-6.00
fully-optional (20mm-AOTF, near-field, 2-dimensional scan)	6.90-8.28

*) nominal to +20% margin values.

Table) NIRS4/MacrOmega power consumption

Component case	Power consumption (*)		
	cooling & pointing	acquisition & pointing	processing
nominal (15mm-AOTF)	28.8	42.0	12.0
fully-optional (20mm-AOTF, 2-dimensional scan)	37.2	50.4	12.0

*) including 20% margins.