



Surface science on Phobos with the navigation cameras of the MMX IDEFIX rover

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Introduction

Phobos, the largest and closest moon to Mars, is the principal target of the Martian Moon eXploration (MMX) JAXA mission, which is scheduled for launch in 2026. The mission will orbit Phobos and perform multiple fly-bys of Deimos, send a rover to the surface of Phobos (Michel et al., 2022) and retrieve and return $\geq 10\text{g}$ of Phobos regolith back to Earth in 2031 (Kawakatsu et al., 2023; Kuramoto et al., 2022). The primary objective of the mission is to provide a definitive answer regarding the origin of the martian moons.

The mission comprises an orbiter and a small rover, designated IDEFIX. The latter is a contribution from the Centre National d'Études Spatiales (CNES) and the German Aerospace Center (DLR). The instrument suite on board the rover will comprise the navigation cameras (a stereo pair), two wheel cameras, a Raman spectrometer and a mini radiometer. The cameras (NavCams & Wheelcams) are a contribution from CNES, whereas the remaining two instruments are provided by DLR.

Instrument description

The navigation cameras (NavCams) are mounted at the top of the front panel of the rover and are tilted down by 23 deg. The mass of the NavCams (stereo bench) is $\sim 526\text{g}$. Four white LEDs are located in between the stereo camera to allow observations during the night. The NavCams consist of a stereoscopic pair with a field of view (diagonal) of 122 deg, a focal length (F) of $\sim 7.9\text{mm}$, a F/8 aperture and a depth-of-field from 35 cm to infinity. The stereo baseline (distance between the two cameras) is 6 cm. Each camera consists of a wide-angle optical lens assembly developed by Lambda-X and a CASPEX 2048 $\times$ 2048 pixels CMOS detector equipped with RGGB Bayer filters provided by

3DPLUS and CNES. The pixel size is 5.5 μm . This corresponds to an angular resolution of 0.6 mrad at the center and 0.9 mrad at the edges, hence pixel scales at 1 metre of 0.6 millimetre and 0.9 millimetre respectively. The distortion amounts to $\sim 17\%$ on the FOV sides. The spectral response of each camera, integrating the properties of both the detector and the optics, extends approximately from 400 to 800 nanometre. The power consumption amounts to ~ 1.2 W.

Science objectives

By performing stereoscopic imaging of the site surrounding IDEFIX, up to the horizon, the navigation cameras aim to provide answers - in a coordinated effort with orbiter and other rover instruments (such as the TENGOO and OROCHI cameras (Kameda et al., 2021) and the MIRS spectrometer (Barucci et al., 2021) on the orbiter, the Wheelcams, miniRAD and RAX on the rover) - to the following main scientific questions of the MMX mission concerning Phobos' surface geology:

- What is the link between geological / topographic features and spectrophotometric properties of Phobos' regolith?
- How does space weathering work on Phobos? Is it Lunar-like or Tagish Lake-like space weathering?
- What is the origin of the colour dichotomy on Phobos?
- What is the occurrence of grooves and craters at small scales?
- What is the boulder/grain size distribution for $D \geq 3$ millimetre particles and how does it compare with other small bodies?
- Are exogenous materials present? If yes, what is their composition and origin?
- How does erosion work for boulders and centimetre-sized rocks on Phobos? How common is boulder cracking and is it thermally or impact driven?
- Is there any evidence of dust transport and levitation on Phobos?

Data processing pipeline

A processing pipeline is currently being developed at the Laboratoire d'Astrophysique de Marseille to transform the raw NavCam data into high-level science products. This pipeline, developed in Python, benefits from a heritage from the Rosetta mission.

The pipeline aims to generate, among others:

- Radiometrically and geometrically calibrated stereo pairs
- 3D digital terrain models (DTMs) of the observed scenes
- Albedo and color maps
- Low resolution spectral maps
- Maps of gravitational heights and slopes

Conclusion

The CNES/DLR IDEFIX rover of the JAXA MMX mission is scheduled to be delivered to the surface of Phobos in December 2028 or early 2029. The goal of the rover is to travel across the surface of Phobos for at least 100 days, with autonomous guidance provided by the NavCams. During this expedition, the first of its kind on a low-gravity body, the images collected by the NavCams will provide elements of answers to a number of scientific questions, including but not limited to the origin of the color dichotomy and the nature of space weathering processes on Phobos.

MMX NavCams: Celia Pimorin (LAM), Jean Bertrand (CNES), Emile Remeteau (CNES), Emilie Robert (CNES), Cedric Virmondois (CNES)