LaRa (Lander Radioscience) on the ExoMars 2020 Surface Platform.

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Introduction: The LaRa (Lander Radioscience) experiment is designed to obtain coherent two-way Doppler measurements from the radio link between the 2020 ExoMars lander and Earth over at least one Martian year. The Doppler measurements will be used to observe the orientation and rotation of Mars in space (precession, nutations, and length-of-day variations), as well as polar motion. The ultimate objective is to obtain information / constraints on the Martian interior, and on the sublimation / condensation cycle of atmospheric CO_2. Rotational variations will allow us to constrain the moment of inertia of the entire planet, including its mantle and core, the moment of inertia of the core, and seasonal mass transfer between the atmosphere and the ice caps.

The LaRa instrument: The Surface Platform of 2020 ExoMars on the Martian surface will house a radio science experiment called LaRa (Lander Radioscience) to support specific scientific objectives during the ExoMars mission. LaRa has been designed to transpond an X-band signal transmitted from an Earth ground station, back to the Earth. The relative radial velocity of the Earth and the Martian lander is inferred from Doppler effects measured at the Earth ground stations. The Doppler shifts are measured from the Doppler tracking observations called "Two-way" by comparing the frequency of the radio signal received from LaRa with the corresponding frequency of a ground-based reference signal.

As LaRa performs a down coherent conversion of the uplink carrier, the Masers of the Earth's ground stations ensure the frequency stability of the LaRa radiosignal. The downlink carrier frequency is related to the uplink carrier by a multiplicative constant, the transponder ratio (880/749).

LaRa uses at least two X-band antennas to communicate with the Earth, one for receiving the signal and one (possibly duplicated) for re-transmitting the signal. In order to minimize the radio blackout during the observation period of the Earth in the Martian sky, LaRa's antennas are designed to obtain an optimal antenna gain centered on an elevation (angle of the line-of-sight from lander to Earth) of about 30-55 degrees.

Finally, the strong energy/mass restriction (Power ≤ 39 Watt – Total Mass transponder + antennas ≤ 2.150 kg) and the payload interfaces compatibility (with thermal control system (TCS), data handling system (DHS) and electrical power system (EPS)) has introduced significant additional constraints in the final design of LaRa. The transponder design maintains the coherency of the signal, and the global precision on the Doppler is expected to be better than 0.1 mm/s at a 60 second integration time (compared to the instrument precision requirement at the level of 0.02 mm/s at a 60 second integration time).

After landing, the transponder will be operated when an Earth ground station is available and when the Earth is in the sky of the lander. The position of the lander will be determined with the first passes as well as from the landing site characteristics. It is expected that LaRa will operate twice per week at least during the whole mission lifetime (twice per week during the minimum guaranteed mission and during the extended mission, with a possible relaxation to once per week during hibernation). No operation is required at solar conjunction and for a solar elongation angle less than 5 degrees. The tracking will be performed at the time of the Martian day when the line-of-sight of the Earth ground station is at an elevation of about 30-55 degrees (better LaRa antenna gain).

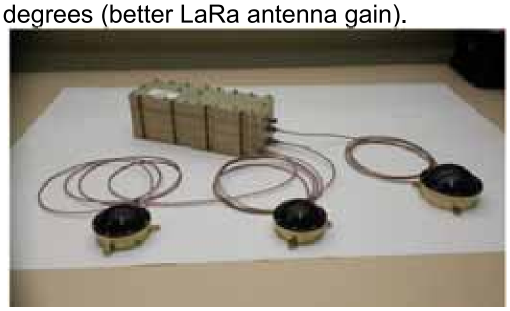

Figure 1: The LaRa transponder and its antennas (1 receiving antenna RX, 2 transmitting antennas TX).

The LaRa science: The Doppler measurements will be used to observe the orientation and rotation of Mars in space (precession, nutations, and length-of-day variations), as well as polar motion. The ultimate objective is to obtain information/constraints on the Martian interior, and on the sublimation/condensation cycle of atmospheric CO_2. Rotational variations will allow us to constrain the moment of inertia of the entire planet, including its mantle and core, the moment of inertia of the core, and seasonal mass transfer between the atmosphere and the ice caps.

Since Mars is oblate and rotating and since the equator is not parallel to the Mars-Sun line (Mars has an obliquity angle of about 25°), Mars reacts as a spinning top to the gravitational torque exerted by the Sun. As a consequence, the rotation axis and the planet slowly move in space around the perpendicular to the orbital plane (see Figure 2). The time needed to perform one cycle around the orbit normal is about 171,000 years with a speed on the precession cone (so-called precession rate) of about 7.6 arcsecond/year at present. A first objective of LaRa is to very accurately determine the precession rate. Since **precession** is inversely proportional to the polar principal moment of inertia, LaRa will be able to accurately determine the moments of inertia of Mars, providing important constraints on the interior structure.

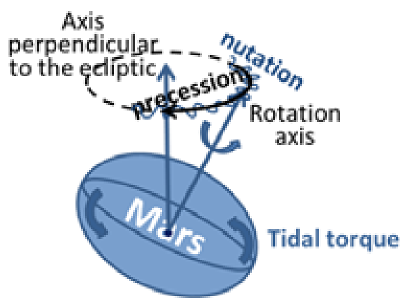

Figure 2: Representation of precession and nutation of Mars.

Because of the elliptical orbital motion of Mars and the orbital changes due for instance to interaction with other Solar System bodies, the gravitational torque on Mars changes with time. The variations in the torque induce periodic changes in the precession as well as variations in the obliquity, called **nutations**. The resulting motion of the pole due to precession and nutation is wiggly as illustrated in Figure 2. The periods of the nutations are related to the periods of the orbital motion and to the periods of the orbital perturbations. The largest of these periodic nutations has a period of half the orbital period. Detailed explanations can be found in the encyclopedia chapter of Dehant and Van Hoolst [1] and Van Hoolst and Rivoldini [5], in the book of Dehant and Mathews [2], and in the Treatise on Geophysics chapters [3] [6]. LaRa will for the first time determine the main nutation terms of Mars.

The **rotation changes** are due to exchange of angular momentum with the atmosphere and to gravitational torques acting on Mars.The rotation rate of Mars is approximately uniform but variations in the **Length-Of-Day (LOD)** have already been observed and are mainly due to exchanges of mass and angular momentum between the atmosphere and surface. These exchanges occur mostly at seasonal periods through sublimation/condensation of the CO_2 polar caps, mass redistributions in the atmosphere, and seasonally changing winds. LaRa will improve current estimates of the LOD variations (known at about 15% level, Konopliv et al., 2011) and thereby will place the best global constraints on the global mass redistribution in the atmosphere and ice caps and the atmospheric angular momentum.

The LaRa experiment will be combined with other ExoMars experiments, in order to retrieve a maximum amount of information on the interior of Mars. Specifically, combining LaRa's Doppler measurements with similar data from the Viking landers, Mars Pathfinder, Mars Exploration Rovers landers, and the forthcoming InSight-RISE lander missions, will allow us to improve our knowledge on the interior of Mars with unprecedented accuracy, hereby providing crucial information on the formation and evolution of the red planet.

References:

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Acknowledgements: This work was financially supported by the Belgian PRODEX program managed by the European Space Agency in collaboration with the Belgian Federal Science Policy Office.