RADIOSCIENCE EXPERIMENTS TO MONITOR ATMOSPHERIC ANGULAR MOMENTUM VARIATIONS ONBOARD THE FORTHCOMING 2018 INSIGHT AND 2020 EXOMARS LANDERS.

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Introduction:

LaRa onboard ExoMars 2020 surface platform and RISE onboard InSight 2018 are radio science experiments designed to obtain coherent two-way Doppler measurements from the radio link between the Mars landers and Earth. The signals at the X-band radio frequencies will be generated and received by Earth-based giant antennas.

The Doppler measurements will be used to precisely determine the variations of the rotation rate (expressed as the Length-Of-Day (LOD) variations) and the orientation of the spin-axis of Mars in space (the long-term precession, polar motion and periodic nutations). These rotational data provide information on the interior structure such as the state, size and composition of the core as well as on the atmosphere of Mars.

The liquid core is expected to modify the periodic oscillations in the spin-axis orientation i.e, nutations. The precession of the spin axis determines the polar moment of inertia (MOI) of the whole planet, which quantifies the mass concentration towards the center and is a major constraint for models of the interior structure of planets. In addition, since the changes in Mars rotation in seasonal scales are mainly due to exchanges of angular momentum between the atmosphere and the ice caps, the measured rotation will deliver information on the Mars CO_2 cycle.

LaRa and RISE will provide precise Doppler measurements from which the motion of the landers in space can be calculated over a time period long enough to detect the signature of interior and to determine the effect of the atmosphere. The ultimate objectives of LaRa and RISE are to obtain information and constraints on the Martian interior, as well as on seasonal and inter-annual mass transfer between the atmosphere and the ice caps.

Atmosphere Surface interaction

The interaction between the solid and fluid layers of the Earth is the major cause of the fluctuations of the Earth rotation. In the absence of external forces, the total angular momentum of the Earth is conserved and any change in the Atmospheric Angular Momentum (AAM) yields a change in the solid planet's angular momentum. The same is true for Mars. Nevertheless, the causes and nature of angular momentum variations can be rather different.

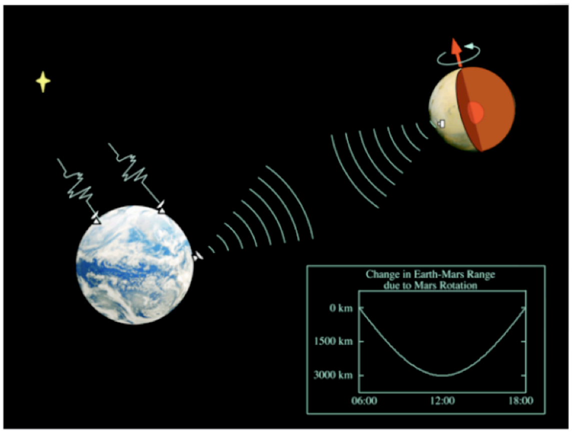

Fig. 1 Rotation of Mars can be measured by radio range and Doppler, with the rotation of Earth measured relative to extragalactic radio sources with very-long-baseline interferometry.

AAM variations of a planet are associated with the global atmospheric mass redistribution and the wind variability. On the Earth, the largest contribution to angular momentum comes from the annual excitation caused principally by the Mousson regime and the seasonal variations of zonal winds. The angular momentum variability of Mars on the other hand is principally due to surface mass redistribution over seasonal time scales. The variation of angular momentum remains much smoother compared to that of the Earth. As a consequence, the amplification of the normal modes of the planet Mars due to the angular momentum is less significant compared to Earth. For both the Earth and Mars, the diurnal angular momentum variations are much smaller compared to the seasonal variations scales (Karatekin et al., 2011).

The angular momentum variations can be expressed by introducing the atmospheric angular momentum excitation functions (Barnes et al., 1983) and the loading effect, represented by the non-dimensional Love numbers (Munk and McDonald, 1960) which depend mainly on the elastic properties of the crust and the mantle. Several authors (Cazenave and Balmino, 1981; Defraigne et al., 2000; Van den Acker et al., 2002; Sanchez et al., 2003, 2004; Karatekin et al., 2006, Karatekin et al., 2011) estimated the seasonal variations of LOD from Viking lander surface pressure measurements as well as from GCM data, which includes the wind contribution in addition.

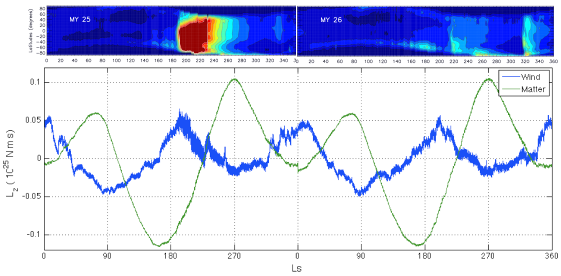

Fig. 2 The variation of axial angular momentum based on MACDA assimilated dataset for years 25 and 26. Zonal means of equivalent visible total dust opacity at 610 Pa as a function latitude and solar longitude are shown above. The effect of dust are visible around Ls 220 for MY25 (Karatekin & Montabone 2014).

Recently, Karatekin & Montabone 2014 have investigated the seasonal angular momentum and rotation variations of Mars using the output from the Mars Analysis Correction Data Assimilation (MACDA) dataset v1.0. Studies of the dynamics of the Martian atmosphere are currently limited by the lack of continuous global observations of dynamical variables with a good temporal and spatial resolution. A promising alternative approach is to assimilate whatever available observations into a general circulation model. MACDA data set contains the reanalysis of fundamental atmospheric and surface variables for the planet Mars over three martian years, produced by assimilating data from spacecraft observations. Temperature and total dust opacities are assimilated into the Mars global circulation model that is in use at the University of Oxford and at the Open University in the UK-LMD-MGCM, covering almost three complete martian seasonal cycles, between martian years 24 through 27. We concentrate in this study the full Martian years 25 and 26. Figure 2 shows the temporal variation of wind and matter components of the axial angular momentum based on MACDA data set for years 25 and 26. The wind component, associated with the relative velocity of the fluid with respect to the solid planet, exhibit high frequency variability as well as seasonal changes. The matter component corresponds to the angular momentum of a rigid rotation of the fluid with the planet, and is also called the pressure term. Its variation is mainly seasonal. The effect of dust is visible in MY 25 around Ls =220°.

The angular momentum exchange between the surface and the atmosphere, alters the planetary rotation, causing variations on the order of millisecond in Martian LOD over seasonal time scales whereas the polar motion effect is predicted to be in the order of tens of milliarcsecond (Karatekin et al., 2011).

The parameters of the rotation of Mars have been determined using radio Doppler and ranging measurements from Martian orbiters and landers. These measurements had a signature on the measured radio signal due to the rotation of Mars about its spin axis and to the changes in Mars' orientation. Accurate radio tracking of Mars orbiters is being performed nearly continuously since the arrival of MGS in 1997. Since then, the radio science data from orbiters (MGS, MO and MRO) combined with the data from Viking and Mars Pathfinder landers have been continuously improving the determination of the Mars rotation parameters (see Konopliv et al., 2011). Figure 3 shows the LOD variations computed from the GCM data as well as MACDA data for years 25 and 26 compared with the spacecraft observations from Konopliv et al., (2011). AMES (Haberle 2008) and LMD GCM (Climate Data Base version 4.2) have different assumptions for the dust content of the atmosphere. MACDA and AMES GCM have higher temporal resolution whereas LMD MCD database considers only typical days over a martian month, hence LMD data is relatively smoother. The overall agreement between the observed and modeled ΔLOD is fairly good. Nevertheless, the present knowledge of LOD is not sufficient enough to differ between models and to constrain Mars CO_2 cycle or winds. In addition, the accuracy of observations does not allow to determine nor the polar motion neither the interannual variability of LOD.

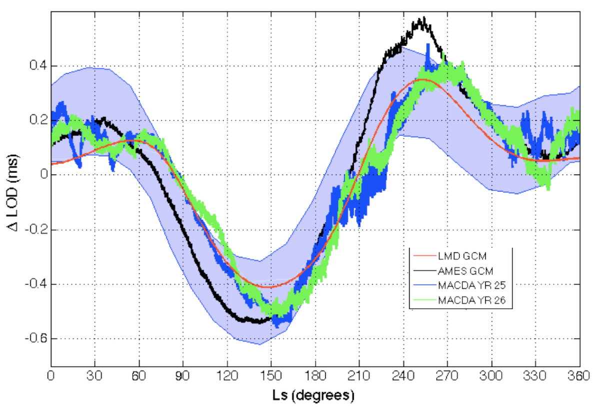

Figure 3. LOD variations computed from the GCM data)) as well as MACDA years 25 and 26 compared with the spacecraft observations from Konopliv et al., 2011 (blue shadowed region). The thickness of the shadowed region corresponds to the measurement uncertainties. (Karatekin & Montabone 2014)

Forthcoming Radio Science Experiments

Radio tracking of ExoMars Surface Platform (LaRa) and InSIght (RISE) in X-band over will improve the current precision on LOD more than an order of magnitude (See Figure 4). Such a precision will permit to provide constraints on the details of the physical processes taking part in the angular momentum variations of the Martian atmosphere. In addition, with such a precision on ΔLOD and with longer tracking coverage it might be possible to see the inter-annual variations of the global-scale cycling of CO2 on Mars that could arise from the dust storm variability.

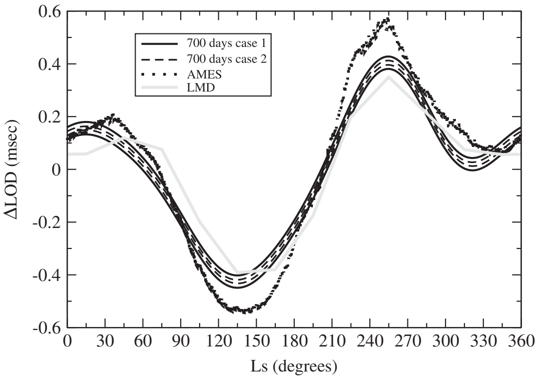

Fig. 4: ΔLOD estimates from simulated Lander radio science experiment with a direct link between Mars and the Earth in comparison with those based on LMD and AMES GCM. The predicted uncertainty ranges of Lander radio science experiment are shown between the corresponding lines (See Le Maistre et al., 2012 for further details.)

Conclusion:

Forthcoming Radio Science experiments RISE and LaRa, are expected to improve current knowledge of Mars rotation parameters by at least an order of magnitude. They will provide information not only on the interior structure but also on the details of the physical processes taking part in the seasonal and inter-annual angular momentum variations of the Martian atmosphere and the sublimation / condensation cycle of atmospheric CO_2.

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