A STUDY ON THE SATELLITE-TO-SATELLITE TRACKING TO DETECT MARS ROTATION VARIATIONS. T. Iwata[1], K. Matsumoto[2], Y. Ishihara[2], F. Kikuchi[2], Y. Harada[3], and S. Sasaki[2], [1]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency (3-1-1 Yoshinodai, Sagamihara, Kanagawa 252-5210, Japan; iwata.takahiro@jaxa.jp), [2]National Astronomical Observatory of Japan, [3]Shanghai Astronomical Observatory, Chinese Academy of Sciences, China.

Introduction: MELOS (Mars Exploration with Lander-Orbiter Synergy) is a Japanese Martian explorer which is under proposing to be launched around 2020. It will consist of an orbiter for meteorology observation (hereafter, the Orbiter) and a lander for entry-descent-landing demonstration (hereafter, the Lander). As one of the missions of MELOS Orbiter and Lander, we are proposing areodetic observations using space geodetic technologies. We have shown that the four-way Doppler measurements and inverse VLBI can determine the state of the core (liquid or solid), estimate its radius if it is liquid, and figure out the quantities of seasonal surface mass redistribution [1]. For the purpose of reducing the mass and electric power on the Lander, we modified the space geodetic technologies to Doppler measurements with satellite-to-satellite tracking (SST).

Mission goal: Variation of planetary rotation provides us information concerning both the interior structure and the surface mass redistribution. Such information is valuable for elucidating not only present condition but also evolution of a planet as a system. Precession and nutation of Mars reflect the present status of the core-mantle sub-system, besides length-of-day (LOD) variation and polar motion of Mars are induced by variation of the atmosphere-cryosphere sub-system.

Two-way tracking of orbiters on Mars were executed to elucidate the physics of Mars. Precession and LOD variation have been measured by means of tracking data of Viking 1 and 2 [2], and Mars Pathfinder [3]. The results of the Love number k_2 obtained by two Martian explorers: Mars Global Surveyor (MGS) and Mars Odyssey: predict existence of a liquid core inside Mars [4, 5]. Seasonal variations of the polar caps on Mars were estimated mainly based on the laser altimeter data on MGS in conjunction with gravity data [6, 7].

Although Mars' rotation observations by two-way tracking have produced scientific results as shown above, these measurements had limitations in terms of accuracy within the framework of traditional technologies concerning space geodesy and astrometry. Thus, the new configurations of orbiter-to-lander tracking had been proposed for two Martian explorers. To achieve the accuracies in the order of 1 mas (mill-arc second) to detect Martian rotation variation, orbiter-to-lander tracking were proposed for NetLander [8, 9] and ExoMars [10], which have still not been approved as real missions for Mars.

Inverse VLBI is a new technology for space geodesy to improve the accuracy of positioning [11]. One of the remarkable characteristics of inverse VLBI is that the theoretical accuracy of positioning depends only on the observation frequency and does not depend on the distance between the radio sources and the ground stations. For the spacecraft on the Martian orbit, inverse VLBI observations with X-band (8 GHz band) micro-wave will provide the ideal accuracy of 0.3 mm without systematic phase noise, besides conventional differential VLBI reaches to 10 to 60 m depending on the distance between Mars and ground stations. Using the inverse VLBI, we can detect the nutation with the accuracy of 0.1 mas, which can determine the assumed Martian liquid core size with the accuracy of 10 km.

To realize the technique for inverse VLBI step by step, we will demonstrate the inter-satellite communication for the Doppler measurements by SST. The expected accuracy for the LOD observation is 20 micro-second, which can distinguish the contribution for LOD variation by Martian atmospheric pressure, polar ice caps, and winds [12].

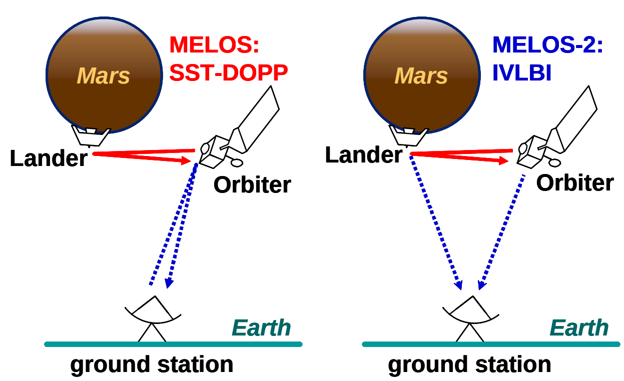

Figure 1. Mission concepts of Mars rotation observations using Doppler measurements by satellite-to-satellite tracking (left), and inverse VLBI (right), which are proposed to MELOS.

Instruments: Satellite-to-satellite tracking (SST) is one of the technologies of space geodesy. A tracking spacecraft transmits radio-wave to a target spacecraft, and the target spacecraft returns the received radio-wave with keeping coherency. Then the tracking spacecraft measures the Doppler shift or phase-shift of the received signal.

Figure 1 shows the mission concepts of Mars rotation observations using space geodetic technologies proposed to MELOS. Doppler measurements by SST (SST-DOPP) will be executed between the Orbiter as a tracking spacecraft and the Lander as a target spacecraft (Figure 1: left). Tracking for the Orbiter will be simultaneously made by 2-way ranging and ranging rate (RARR) at the ground station. In the case of inverse VLBI (IVLBI) on the future mission such as MELOS-2, phase-shift measurements using multi-frequency micro-waves, *ex*. at S and X-band (2 and 8 GHz), will be executed at the Orbiter (Figure 1: right). Tracking for both the spacecraft will be simultaneously made by 1-way multi-frequency phase-shift measurements at the ground station.

Figure 2 displays the conceptual block diagrams of inter-satellite communication instruments for Mars rotation measurements. Components and signal lines with red and blue color are for SST-DOPP and IVLBI, respectively. Carrier signals of micro-wave are transmitted from a transmitter (Tx) on the Orbiter through a diplexer (DIP) and antennas (ANT). The transponder (TRP) on the Lander relays the signals with coherent frequency conversion, and then the receiver (Rx) on the Orbiter receives the returned signals. All the signals are coherently locked to the frequency standard signals generated by the ultra-stable oscillator (USO). For IVLBI, micro-wave telecommunication will be done using multi-frequency (MF) bands such as S and X-band. The Doppler shift of the returned signal is measured by a Doppler counter (DPC) for SST-DOPP. Phase shift of the returned signal will be obtained by a phase-shift counter (PHC) for IVLBI.

Summary: We propose the precise observations of Mars rotation using the Doppler measurements by satellite-to-satellite tracking (SST) for the Japanese future exploration for Mars; MELOS (Mars Exploration with Lander-Orbiter Synergy). The Doppler shift of the returned signal from the MELOS Lander is measured at the MELOS Orbiter. This technology of space geodesy is expected to realize the accuracy for the length-of-day (LOD) observation of 20 micro-second, which can distinguish the contribution for LOD variation by Martian atmospheric pressure, polar ice caps, and winds. It also demonstrates the inter-satellite communication for the future inverse VLBI which will remarkably improve the positioning accuracy of Martian spacecraft.

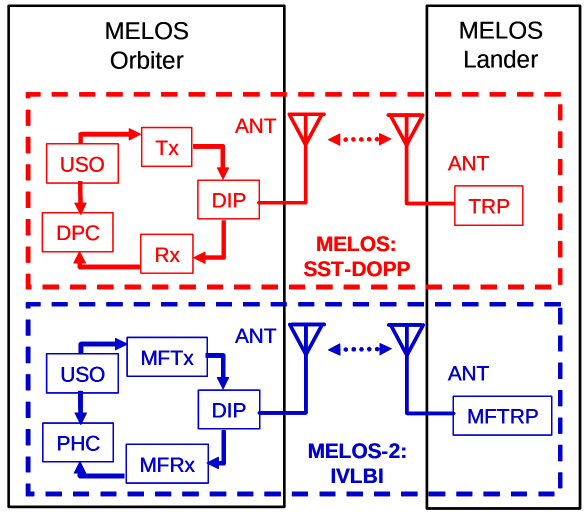

Figure 2. Conceptual block diagrams of inter-satellite communication instruments for Mars rotation measurements. Components and signal lines with red color are for Doppler measurements by satellite-to-satellite tracking (SST-DOPP), and those with blue color are for inverse VLBI (IVLBI). Abbreviations are described in the text.

References: [1] Iwata T. et al. (2011) *LPS XLII*, Abstract #1132. [2] Yoder C. F. & Standish E. M. (1997) *JGR* 102, 4065-4080. [3] Folkner W. M. et al.(1997), *Science* 278, 1749-1751. [4] Yoder C. F. et al. (2003) *Science*, 300, 299-303. [5] Konopliv A. S. et al. (2006) *Icarus*, 182, 23-50. [6] Smith D. E. et al. (2001) *Science*, 294, 2141-2146. [7] Matsuo H. and Heki K. (2009) *Icarus*, 202, 90-94. [8] Barriot J. P. et al. (2001), *Adv. Space Res.*, 28, 1237-1249. [9] Yseboodt M. *et al*. (2003) *JGR*, 108, 12-1. [10] V. Dehant, et al. (2009) *Planet. Space Sci*., 57, 1050-1067. [11] Kawano N. et al. (1999) *J. Geod. Soc. Japan*., 45, 181-203. [12] Van den Acker E. et al. (2002) *JGR* 107, 9-1.