# Improvement of the MARSIS On-Board SW, on the Mars Express Mission. Preliminary Scientific results on Phobos and Mars


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**The MARSIS instrument on ESA's Mars Express spacecraft, known for its role in the discovery of liquid water on the Red Planet, has received a major SW upgrade that allows to see beneath the surfaces of Mars and its moon Phobos in more detail than ever before. The MARSIS software was originally designed over 20 years ago; after decades of fruitful science and having gained a good understanding of Mars, we wanted to push the instrument's performance beyond some of the limitations required back when the mission began. The new SW implemented on Mars Express by ESA, includes a series of upgrades that improve signal reception and on-board data processing to increase the amount and quality of science data. There are many regions near the south pole on Mars in which we may have already seen signals indicating liquid water in lower-resolution data, the new SW will help us more quickly and extensively to study these regions in high resolution mode and confirm whether they are home to new sources of water on Mars. It really is like having a brand-new instrument on board Mars Express almost 20 years after launch. The following boxes illustrate the instrument improvements, comparing the performances before and after the on-board Software upgrade.**

## MARSIS PERFORMANCE

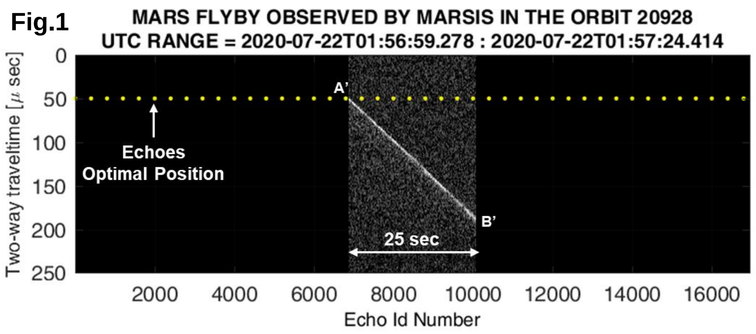
### BEFORE SW UPGRADE

**IMPROVEMENT OF:**
**SURFACE TRACKING & RAW DATA SEGMENT DURATION**

### AFTER SW UPGRADE

**Previously, to study small, important features on Mars, and to study Phobos at all, we relied on a complex on-board SW configuration called Super Frame (SF), that stores many high-quality data very quickly and severely limits how long we can observe a target before the instrument's on-board memory fills up. By discarding useless data, the new SW allows to explore larger area with each pass. Where we were previously limited to 25 seconds per day, now we can record 134 seconds of observations. The mechanism for positioning the collected Echoes within the Receiving Window has also been improved, allowing to avoid harmful signal losses.**

**Fig.1**




**A generic MARSIS Super Frame acquisition is shown in Fig. 1. The Echo identified with the letter A' is correctly positioned in the Receiving Window, while the last collected Echo (B') was not placed correctly, causing loss of signal tail, of about 100us. The flyby duration was only of 25 sec, that correspond to a strip of about 100 km, on Mars surface. The ground track is shown by the yellow segment of Fig.3.**

**Fig. 3**

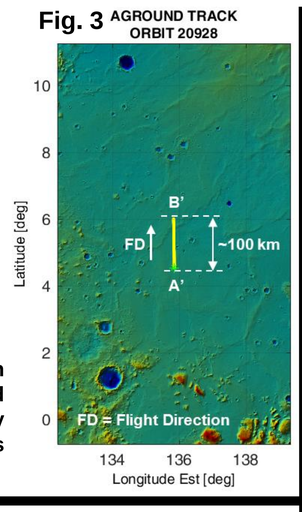



**Fig. 4**

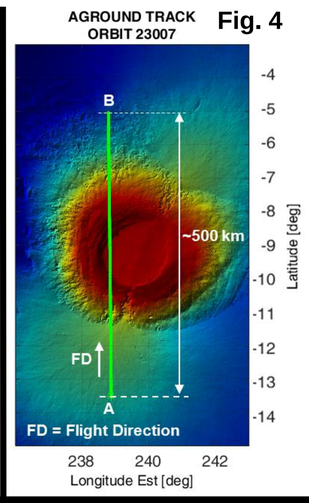



**Fig.2**

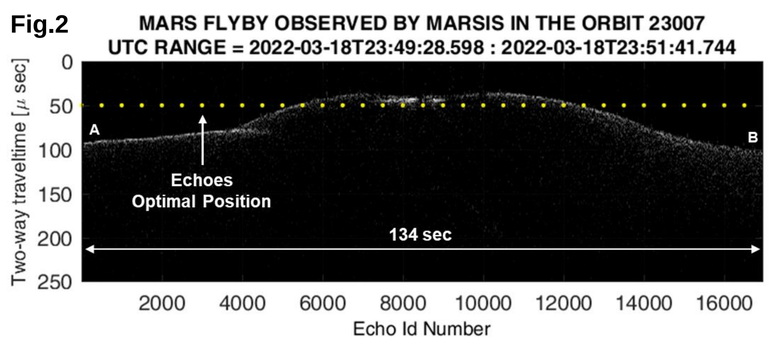



**Fig. 2 shows MARSIS Raw data collection over Arsia Mons Volcano. The flyby duration is now of 134 sec, that correspond to a strip of about 530 km on Mars surface. The position of the Echoes slightly deviate from the optimal value of 50 μs, allowing however to record all Echoes without any signal loss. The ground track is shown by the green segment of Fig.4.**

### BEFORE SW UPGRADE

**IMPROVEMENT OF:**
**PHOBOS MINIMUM DETECTABLE RANGE**

### AFTER SW UPGRADE

**The new MARSIS on-board SW was primarily designed to optimize observations of Mars' moon Phobos, which was not thought of as a possible target when Mars Express was launched, therefore the MARSIS instrument was originally conceived to observe exclusively Mars. As a result, it was designed for use at the typical distance between the spacecraft and the planet's surface – more than 240 km. The new SW upgrade allows MARSIS to be used at much closer distances (the minimum detectable range is now set at 45 km). The new on-board SW also optimizes the Receiver Gain, adaptively during an observation, improving the dynamic range of the recorded science data. In the next years [2023 : 2025], MARSIS will be able to observe Phobos even closer, at distances below 50 km, providing new opportunities to study this unique celestial body, and contributing to solving the mystery surrounding Phobos' origin.**

**Fig.5**

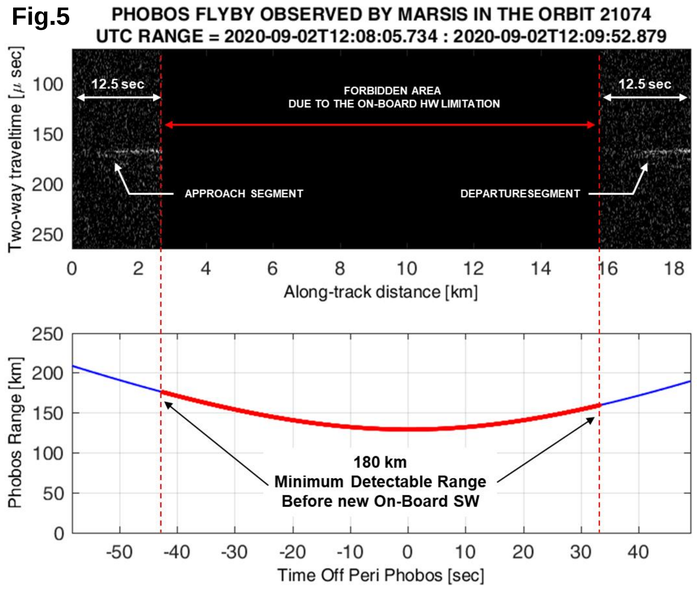



**Fig.7**

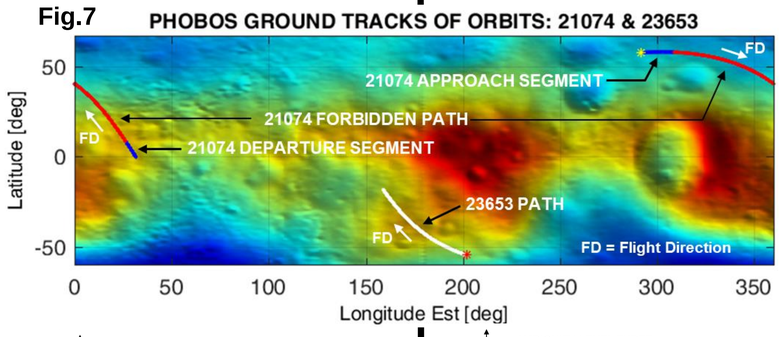



**Fig.8**

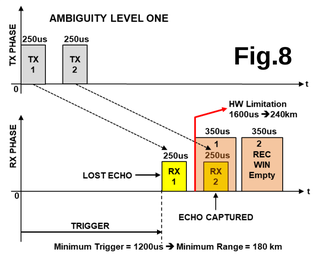



**Fig.9**

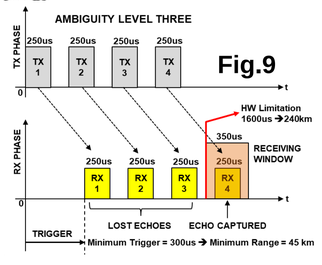



**Fig.10**

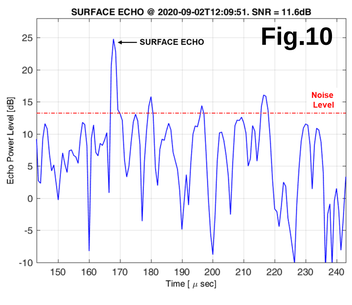



**Fig.11**

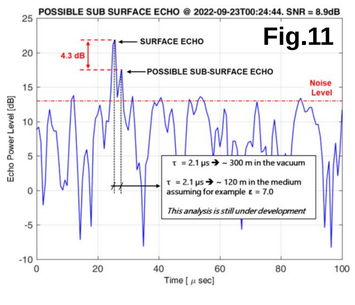
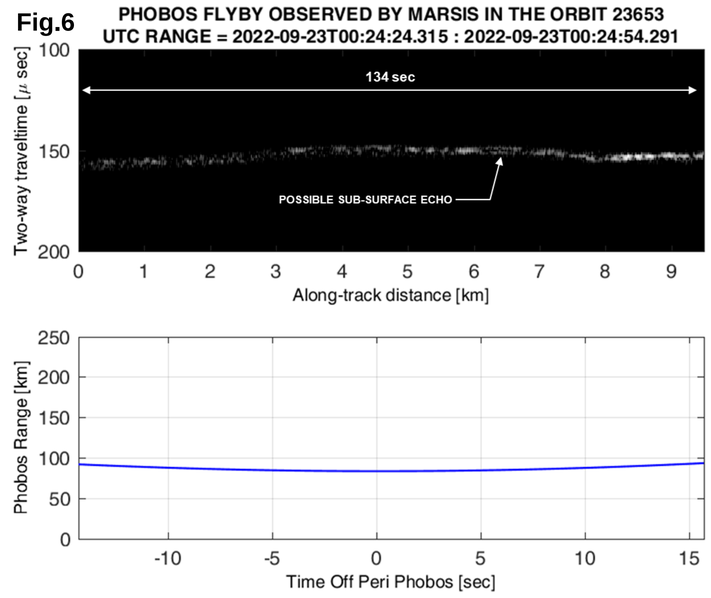



**Fig.6**




**The scientific results of one of the last flybys operated with the original on-board SW are shown in Fig. 5, while the ground tracks of the two acquisition segments (approach and departure) are shown in blue color of Fig 7. The red segments highlighted in Fig. 5 and Fig. 7 represent the blind zone of the radar, due to the on-board Hardware block, necessary to maintain separated the transmission and reception phases. Unfortunately, this limitation prevented the observation of Phobos when its distance from the radar is less than 240 km. A particular configuration, called "Range Ambiguity," was every time loaded, via nominal uplink Tele-Commands, to partially override the HW protection zone, reducing the minimum observation distance from 240 km to 180 km, as sown in Fig. 8. A generic single Echo of the flyby, is shown in Fig. 10 with a SNR of ~ 11.6 dB without evidence of subsurface reflections.**

**The science results of the latest Phobos flyby (23/September/2022), are show in Fig. 6. This flyby offered the great opportunity to test the performance of the MARIS SW upgrade, with a minimum distance of only 83 km from the Phobos surface. Transmitting four pulses and Implementing an ambiguity level of factor three, it was possible to further reduce the minimum detectable distance, from 180 km to 45 km, as shown in Fig. This flyby was also very important, due to the presence of weak secondary Echoes which could have been generated by discontinuities in the subsurface, like cavities, layers of different materials, or by surface lateral clutter, the study is still on-going. The generic possible subsurface Echo is shown in Fig.11. Despite the very close distance, the SNR is only of 9 dB, because for Safety Test Requirements, the TX pulses duration was set to 30 us (nominal value is 250us) causing a power loss of ~ 9dB. This Radiated Power Limitation Requirements, it has now been removed. The ground track of the flyby is shown in white color in Fig. 7**


*Acknowledgment. The MARSIS project is founded by the Italian Space Agency (ASI), under the agreement ASI-INAF 2019–21-HH.0.*