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Mars Express investigations of Phobos and Deimos

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ABSTRACT

The Mars Express mission was launched in June 2003 and was inserted into orbit around Mars in December 2003. Its main objective is to study the Mars' subsurface, surface, atmosphere and interaction with the solar wind. A secondary objective is to study the martian moons, in particular the largest one Phobos, thanks to a near polar and elliptical orbit which allows the spacecraft to perform close flybys about every five months. The Mars Express data not only consist of high-resolution 3D color images, but also astrometric images, spectra from 0.18 to 20 μm, radar echoes, Doppler signals from gravity experiments, and ion data. A new view of the moons has emerged from this data set, favoring now the idea that they are not captured asteroids, but rather the result of a re-accretion following a major impact on Mars. This unique set of data is available in the ESA Planetary Science Archive (PSA) and mirror imaged in the NASA Planetary Data System (PDS). This paper presents an overview of the Mars Express Phobos flybys, the specificities of their operations and the scientific achievements.

1. Introduction

An important objective of the Mars Express mission (Chicarro et al., 2004) is to study the martian moons. In particular the aim is to characterise them in great detail, to constrain theories of their origin and evolution, and to prepare future missions of exploration (e.g. Lee, 2011; Michel et al., 2011; Oberst et al., 2012). Mars Express has been orbiting the red planet since 24 December 2003. Due to its near-polar and elliptical orbit which brings the spacecraft beyond 10,000 km from the Mars' surface, Mars Express can provide its instruments with a unique opportunity to observe Phobos every five months. Mars Express is the only orbiter

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currently around Mars that can observe the "far side" of Phobos. Deimos can also be scrutinized, although from much larger distances. The on-board instrumentation, designed to study Mars, is very well suited for the observations of the moons, and in particular Phobos. This article gives an overview of the Mars Express observation planning (Section 2), and a summary of the main results achieved so far (Section 3). Section 4 explains the need to acquire more measurements during an extended mission phase.

2. Mars Express operations at Phobos and Deimos

2.1. Flybys opportunities

Given the polar and elliptical orbit of the Mars Express spacecraft, designed to scan the whole planet at closest distance over one martian year, and the near-circular and equatorial orbit of Phobos, encounters between those two bodies take place every five and a half months (Fig. 1). The number of flybys, the geometry and the distances are different from season to season. There is a risk of collision when the trajectories of both satellites intercept. In this case, an avoidance maneuver is planned in advance to increase the difference of phase between the moon and the spacecraft during the orbit in question. When there is no risk of collision, it is theoretically possible to optimize for the closest possible flyby by adjusting the phasing of Mars Express along its orbit. This has a cost in terms of fuel usage, however, it can be reduced if done months in advance. In any case, an encounter is not allowed within less than 50 km from the center of Phobos for safety reasons. Safety limits are established based on two sources of uncertainty. On the one hand, the orbit is propagated over a long time period, sometimes years. On the other hand, a safe mode can disturb the orbit of Mars Express shortly before a flyby. Optimization were studied and performed for the flybys in July 2008 and March 2010. A similar operation could have been done in 2012, but this conflicted with a trajectory manoeuvre of Mars Express to support the atmospheric entry of the NASA mission MSL-Curiosity. An optimization has already been planned for two close flybys in December 2013 and October 2014. As we can see in Fig. 5, only some alignments yield close fly-by opportunities. During every flyby season there is always a moment in time when the Mars Express orbit intersects the Phobos orbit. For safety reasons, close fly-bys are not performed when the orbits are too close, as orbital disturbances due to a potential safe-mode can change the phasing and lead to a collision. However, it is safe to perform a close fly-by during some orbits just before or after the moment the Mars Express orbit intersects the Phobos orbit.

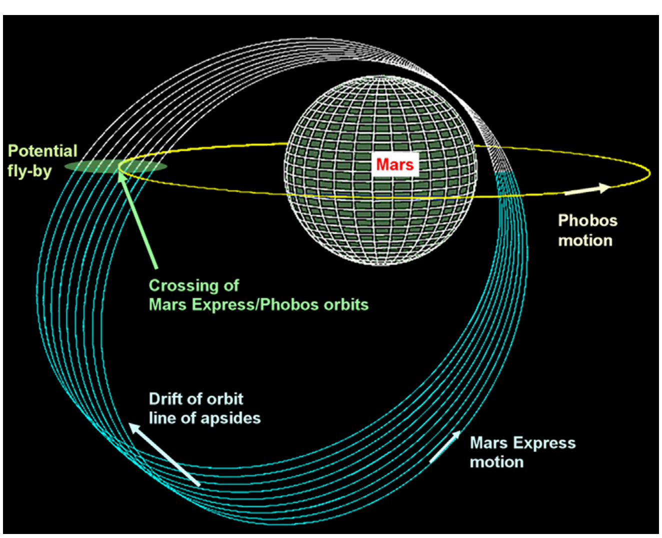

Fig. 1. Illustration of Mars Express' Phobos flybys. Phobos orbits Mars in a nearly circular, equatorial orbit. Mars Express orbits Mars in an elliptical (~250 × 10,000 km^2), quasi-polar orbit. Mars Express' orbit drifts westward over time due to precession of its orbit plane and of its line of apsides, induced by the gravity field of Mars (mainly its dynamical flattening). Once every 150 days, there is the opportunity to perform close flybys.

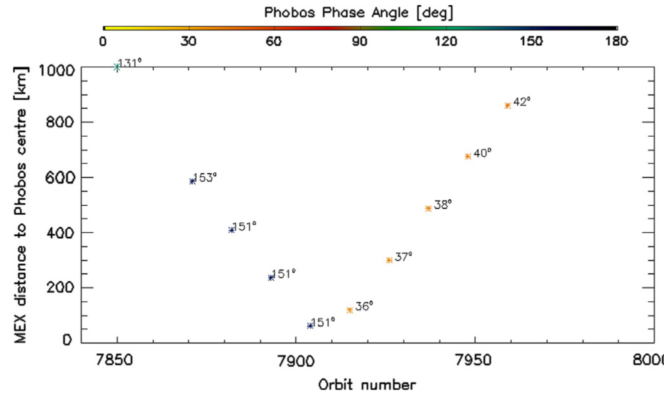

Fig. 2. Phobos flyby season in Spring 2010. Each flyby is plotted as a function of distance to the center of Phobos (*Y* axis) and Mars Express orbit number (*X* axis). The number next to each data point is the phase angle. The first half of the season corresponded to flybys on the night-side of Phobos, the second half on the day-side.

One of the most interesting flyby seasons took place in the Spring of 2010, with a total of 10 flybys within 1000 km (see Fig. 2) and a minimum approach distance of 77 km from the center of the moon. This unique situation was made possible by combining a flyby season with a major orbital maneuver, which was needed to improve the science return of the mission on the long-term. Originally, the closest approach was expected to be around 62 km. However, a slight over-performance of a maneuver a few days before the flybys induced a risk of an occultation of Mars Express by Phobos. This would have blocked radio transmissions, and interfered with Doppler signal-shift gravity measurements that require a direct radio link. This was avoided by an extra maneuver, resulting in a distance at closest approach 15 km higher than planned.

The Mars Express orbit does not allow close flybys at the outer moon Deimos, due to the orbital distance of the smallest martian moon. Nevertheless, observations are planned when the conditions in terms of distance and illumination are acceptable, typically, from about 10,000 km and about every 300 days.

2.2. Planning of operations

The planning of Mars Express is done at three levels (Pischel and Zegers, 2009). Firstly, during the long-term planning process, 6 to 12 months before execution, observational possibilities of flybys are identified. The orbit optimisation tools allow the Flight Dynamics team to identify not only the potentially dangerous cases, but also the safe cases that would yield interesting observations. Simulations are run with various hypotheses on the manoeuvres until an optimum is found between distance, safety and fuel consumption. As there are always competing scientific objectives for each flyby, scientific requests from experiment teams are evaluated, conflicts are anticipated and decisions are recommended at this stage if appropriate. At the second level, during the medium-term planning, 12 weeks before execution, the scientific priorities are confirmed and the actual planning is being prepared. Due to the combination of geometrical, environmental and spacecraft constraints, all experiments cannot always operate simultaneously. Finally, during the short-term planning, the instrument commands are prepared, while science operations are fine-tuned if needed.

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