

Mutual Event Observations of the Martian moons by SRC on Mars Express

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Abstract

The positions of the Martian moons are determined in so-called "mutual event" images acquired by the Super Resolution Channel (SRC) of the High Resolution Stereo Camera aboard Mars Express. These images depict either of the moons *and* the Earth-Moon system, the Galilean moons, the Martian surface, a star or a star field. Such mutual event observations are obtained on a regular basis with the SRC and support the determination of ephemerides for the two satellites.

1. Introduction

Astrometric observations are critical for studies of positions or orbits of planets and satellites. Past SRC astrometric observations containing Phobos or Deimos alone require accurate spacecraft pointing information or means to consider pointing offsets or random errors [5, 6, 7, 11].

Recently, we focused on mutual event observations containing objects filling several pixels in the image, e.g. both moons or either Jupiter or Saturn in the background, and determined the relative angular separation between the imaged bodies. For these kinds of observations the pointing of the spacecraft is irrelevant [13]. Here, we report on the analysis of images that depict either of the moons and the Earth-Moon system, the Galilean moons, the Martian surface, a star or a star field. These objects are very small and appear as point like light sources that are distorted by the SRC's specific point spread function. This requires special care to be taken when the data is reduced.

2. Observations

Table 1 provides an overview of existing mutual event observations from the start of the Mars Express mission in 2003 until March 2018. For all available Earth-Moon system observations the Moon is taken as reference object as the Earth itself is overexposed. This is

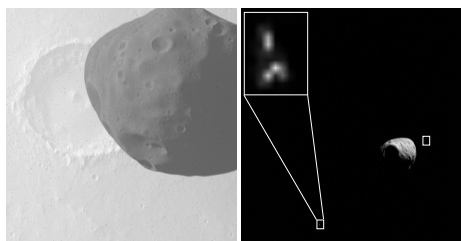


Figure 1: Left: Phobos above the Martian surface (SRC image HC266_0004), right: Phobos and two stars (image HC563_0005) [both ESA/DLR/FU Berlin].

Table 1: Number of images showing mutual events.

Martian moon	other object	# images
Phobos	star(s)	484
Phobos	Earth-Moon system	54
Phobos	Galilean moons	181
Phobos	Martian surface	27
Deimos	star(s)	91

a result of long exposure times necessary to observe Phobos.

3. Methods

The actual measurement is the determination of the image coordinates of the depicted bodies' center of figures (COFs). To support the measurements in given SRC images, synthetic images of Phobos and Deimos are computed. To this end, the observation geometry is simulated using the NAIF SPICE toolkit as well as shape models [10, 12], updated rotational models ([9]) and the parameterless Akimov disk function [4, 8], which describes the photometric behavior of the surface. The simulation is then used to detect the moon in one image (reference image) of each series. The part of the image containing only the detected moon

is used as a template for the matching process in all other images of this specific observation series. Since the COF location is known for the simulation, its location in the image can be easily determined once a good match between observation and simulation is achieved [13].

The SRC images are affected by a complex point spread function (PSF) owing to which stars appear as triangular objects with diffuse edges (see Fig. 1). A PSF provided by [1] is used to detect a star in the reference image. The section of the reference image containing the star is used as a template for the matching process in all other images. If several stars are contained in one image, each star is separately detected and a separate template is created, to take care of possible (albeit small) position-dependent distortions in the image. The stars are identified by means of the new Gaia catalogue [2].

Due to their small sizes and large distances to Mars Express, the Earth's moon and the Galilean satellites are comparable to point-like sources and the same approach for positional measurements as for stars is applied. In both series observing the Jupiter system all Galilean moons can be detected, i.e. none is occulted by Jupiter. However, in orbit 9463 Io and Europa are located close together making the determination of the separate positions difficult. The identification of the moons is supported by SPICE information.

For images of Phobos above the Martian surface the SRC viewing geometry and s/c position provide good information which Mars surface features (e.g. a crater) can be seen in the image. This provides the means to derive the position of the Martian COF in the image plane and hence the angular separation between Phobos and Mars.

4. Conclusions and Outlook

After successfully reducing mutual event observations involving either both Martian moons, Jupiter or Saturn [13], in this paper we describe the reduction of the remaining mutual events observations, which either show Phobos above the Martian surface or one of the moons with a point-like object in the background. The measured angular separation between the Martian moons and the respective background objects will be compared against existing orbit models, e.g. MAR097 [3] and NOE-4-2015-b. Previous results of [13] show a slightly better agreement between observations and the NOE-4-2015-b orbit model. The new observations are expected to complement the previous data set and yield improved ephemerides of the Martian satellites.

Acknowledgements

This project is supported by the Deutsche Forschungsgemeinschaft (DFG), research grant number OB 124/14-1. The authors thank the HRSC Experiment teams for their successful planning and acquisition of data as well as for making processed data available to the HRSC team.

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