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ASTROMETRIC REDUCTION OF THE MARS EXPLORATION ROVER NIGHT-TIME OBSERVATIONS

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Abstract. In 2003 NASA launched toward Mars two robots, Spirit and Opportunity, in search of answers about the history of water on Mars. They landed on Mars on January 4 and January 24, 2004. Since this date, they have traversed around their landing site to search for and characterize a wide range of rocks and soils that hold clues to past water activity on Mars. Among the science instruments carried by the rovers, the Panoramic Camera (Pancam) is used to determine the mineralogy, the texture, and the structure of the local terrain. The Pancam has also been used to take images of the Martian sky during the night. In particular, the Spirit rover has taken more than 500 night-time images showing Mars' moons Phobos and Deimos. We are performing the astrometric reduction of those images, with the goal of refining further the ephemerides of both satellites. Ephemeris improvements may help future targeting of high resolution images of the satellites from orbiters or other future missions. In addition, we hope to provide new constraints on the orbital evolution of the satellites through these observations and through other recent observations.

1 Description of the work

The astrometric reduction concerns 100 images taken between Aug. 26, 2005 and Dec. 12, 2005 (SOL 585 to 691) with the filters L1 and R1 to R7 embarked onboard the Pancam (Bell 2003). At that time, only a quarter of these images has been fully analyzed (SOL 585, 590 and 607).

The main difficulty of this work resides in the fact that the camera was designed to observe the rocky surface of Mars rather than its sky. Thus, no astrometric calibration parameter (i.e. WCS keywords) exists in the header of the images so that the recognition of the field of views (i.e. identification of reference stars) is difficult. The only starting point to determine the direction aimed by the rover's cameras is the areographic azimuth/elevation of the centre of the image (which is recorded in the header of images) and the presence of Phobos and/or Deimos in the field of view.

The workflow used to reduce the images is described in Fig. 1. The astrometric pre-calibration is made using Aladin (developed at Centre de Donnes de Strasbourg, CDS) (Bonnarel 2000). The positions in the field of views of the Mars' moons are matched with the web service SkyBoT (developed at IMCCE, Paris observatory) (Berthier 2006). Figure 2 shows an example of a calibrated image (SOL 585). The extraction of the photocentre of the reference stars is done with the Photo software (developed by R. Behrend, Genova Observatory). The extraction of the photocentre of Phobos and Deimos is made by aperture photometry using SExtractor (Bertin 1996). Finally, the astrometric reduction is realized with Priam (developed at IMCCE, Paris observatory) (Berthier 1999) using a classical 8 parameters plate constants determination to model the function linking the celestial frame and the rover's camera. All computations are made with respect to the Mars IAU 2000 body-centered reference frame. The location of the rover is taken from Arvidon et al. (2004).

2 First preliminary results

A first result of this work is the determination of the astrometric reference frame of each image which provides the orientation of the camera w.r.t the north celestial pole and its scale factor. The orientation, as expected,

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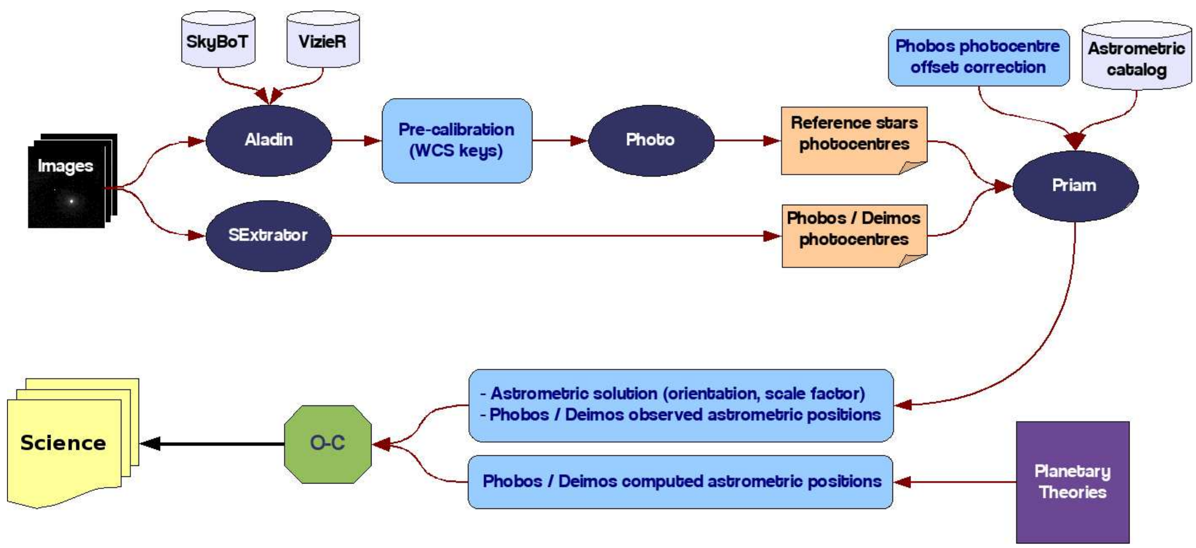

Fig. 1. Astrometric reduction workflow

is unspecified what is normal in an azimuthal device. We see that the scale factor (Table 1), both in X and Y, is well specified at the level of 0.1 arcsec. With a mean value of 56.76 ± 0.11 arcsec/pixel, the measured scale factor is close to the Pancam instrument characteristic value 56.3 ± 0.6 arcsec/pixel (Bell 2003).

Scale factor	Mean ″/px	Std. Dev. ″/px
X	56.72	0.09
Y	56.90	0.11

Table 1. Mean scale factors obtained on 3 SOL (20 images)

The second result of this work is the comparison between the observed and the computed astrometric positions of Phobos and Deimos (O-C). The ephemerides of the Martian moons are computed using Lainey et al. (2006) dynamical solution and are expressed in the IAU J2000 areographic reference frame. The pixel positions of Phobos are corrected from the photocentre/centre of mass offset using synthetic simulations based on areographic physical ephemeris and topographic model of Phobos. At this stage of work, the values of O-C appear large: about 35 km for Phobos and 20 km for Deimos. There are several reasons for that and we have not yet taken them into account at the stage of the work:

- The systematic rover clock drift uncertainties: an uncertainty of 1 sec. in the timing of an image can shift the position of Phobos from 40 to 80 arcsec and the position of Deimos from 10 to 16 arcsec.

- The location of the rover on Mars' surface: we used the coordinates of the landing place of Spirit, but the rover has moved SOL after SOL. An offset of 0.1° in longitude or latitude (i.e. 6 km on Mars surface) of the rover implies a shift of ∼150 arcsec on the celestial coordinates of Phobos and ∼50 arcsec on that of Deimos.

- The systematic uncertainties on Phobos photocentre positions: during the 10 or 15 sec. of integration time, Phobos has moved in the sky. Depending on its apparent velocity at the epoch of acquisition (from ∼40 arcsec/s to ∼80 arcsec/s), this motion can be of 7 to 15 pixels. Thus, the measured photocentre of Phobos becomes the position of photocentre of a trailed object so that an uncertainty of some pixels may appear. This remains to be quantified.

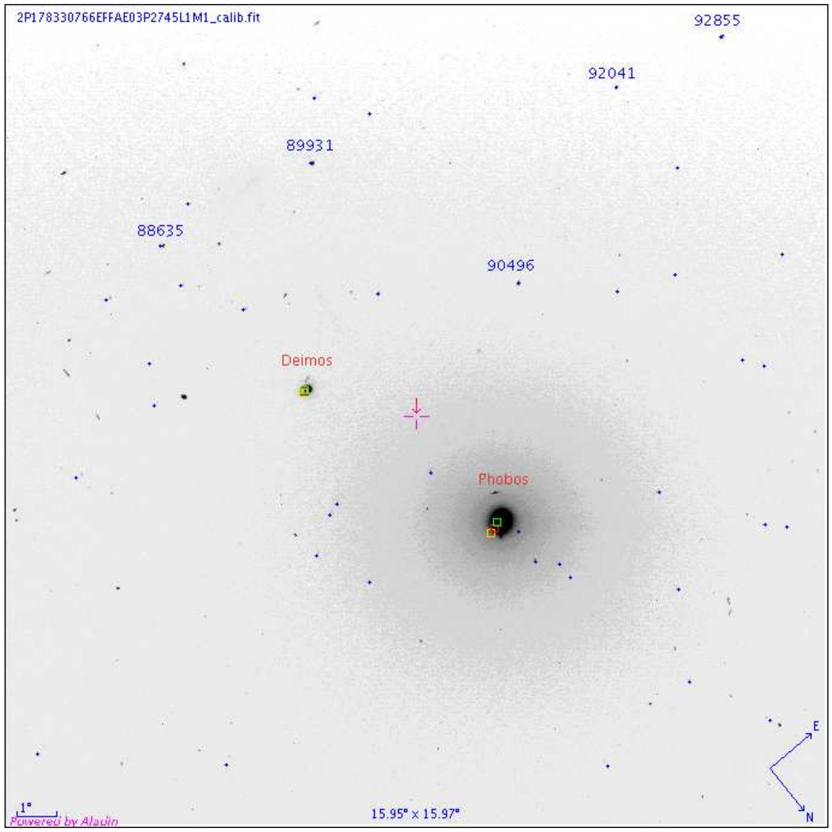

Fig. 2. Calibrated night-time image. The blue marks show HIP stars; the coloured boxes show identification of the Martian moons by SkyBoT and represent the motion of the moons during the integration time (15 s).

3 Future work

The next steps of this work are the analyse of the remaining images and the improvement of the astrometric reduction. First we will improve the computation of the Martian moons ephemeris by including the precession model of Mars and by taking into account the true location of the rover on the surface of Mars. Then we will compare the observed positions of Phobos and Deimos with that computed on the base of the different dynamical solutions of the Martian moons: the Lainey et al. (2006) solution based on all the astrometric observations that are available; the solutions based on the observations realized by MEX and MGS. Finally we should confirm the value of the scale factor that we obtained and we should be able to provide an estimate of the rover clock drift uncertainty.

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