Simulation of Interplanetary Laser Links

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Interplanetary laser ranging can yield highly accurate range measurements from Earth-based stations to interplanetary spacecraft and landers. A software framework that simulates these laser links, and performs the associated parameter estimation in a transparent and modular way has been set up. Using this framework we analyze the potential capabilities of such a system to improve science return of planetary missions. Simulations indicate substantial Mars and Phobos science return, but systematic range and Earth-based station position uncertainties will dominate the influence from the expected 1-mm range precision.

Simulation framework

We have developed a software framework in C++ in which to simulate (interplanetary) missions, with an emphasis on dynamical simulation and tracking system performance. The modular and easily extensible simulation framework is capable of:

- Modeling solar system bodies by interchangeable environment model building blocks.
- Simulating dynamics and variational equations of both artificial satellites and celestial bodies
- Simulating and processing range, range-rate, astrometric, interferometric observations
- Estimating properties of celestial bodies, environment models, system biases, etc. (automatically linked to environment, acceleration and observation models)

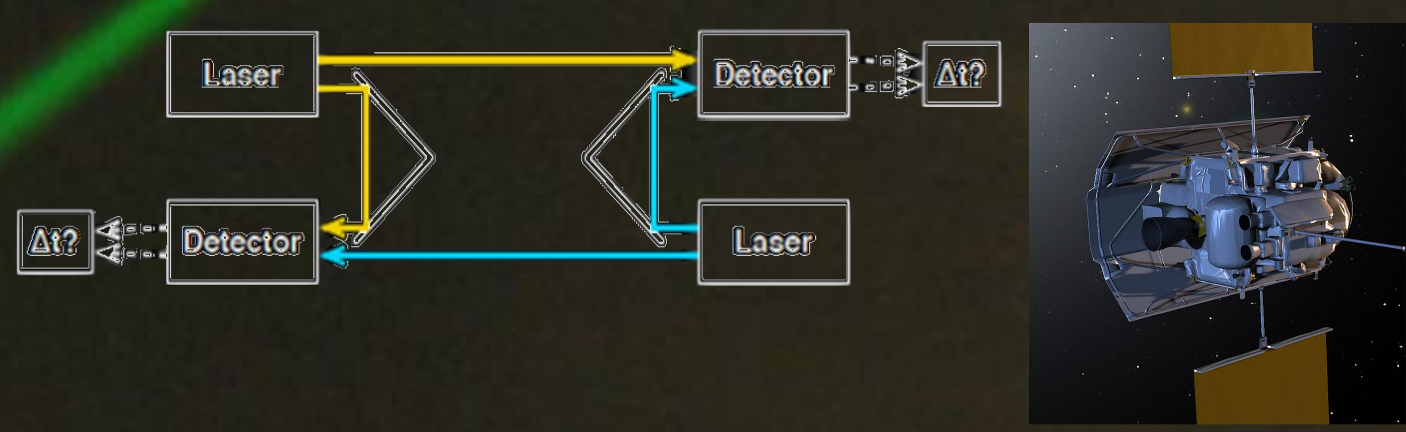

Figure 1: Schematic representations, adapted from Birnbaum et al. (2010) of two-way asynchronous laser ranging, as tested by MESSENGER (pictured)

Phobos laser link simulations

We simulate two-way asynchronous laser links (Fig. 1) from a Phobos lander (Fig. 3) to Earth. We use 1-mm white noise at 60 s integration time, one 15 min. pass/day from 8 SLR stations and estimate a variety of characteristics of Mars and Phobos.

We use so-called 'consider parameters', which are not estimated but known to be uncertain to account for systematic effects: the SLR station positions and observation bias (nominally 5 mm uncertainty for both). The simulation results show that the consider parameters add 10-20 times more to the estimation uncertainty than the white observation noise (see Figs. 2 & 4)

Therefore, expected range precision may not limit system performance; 1-mm range precision systems could perform similarly to 5-mm range precision systems. This firstly indicates the need for highly precise and stable transmission and detection systems, including pulse strength variation (to be addressed in future work), and secondly the need for improved terrestrial reference systems and station displacement models.

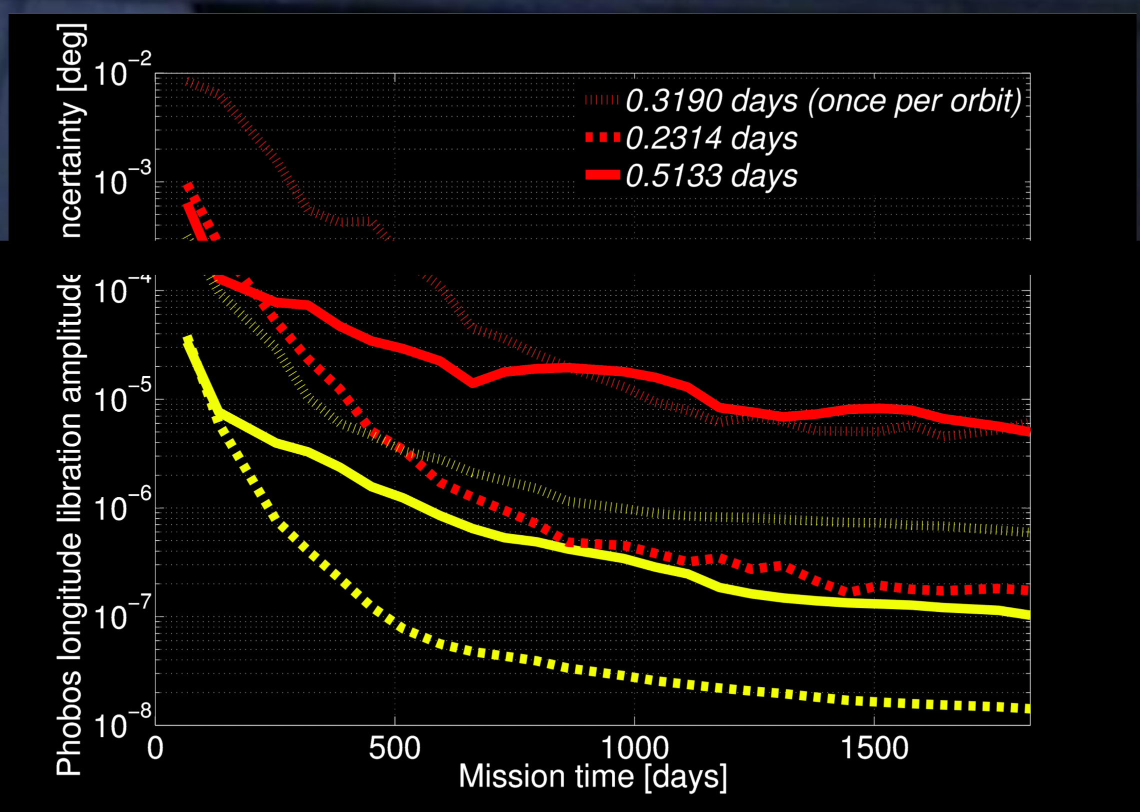

Figure 2: Estimation result of representative short-period librations in longitude. Yellow: without systematic errors. Red: with 5-mm consider errors.

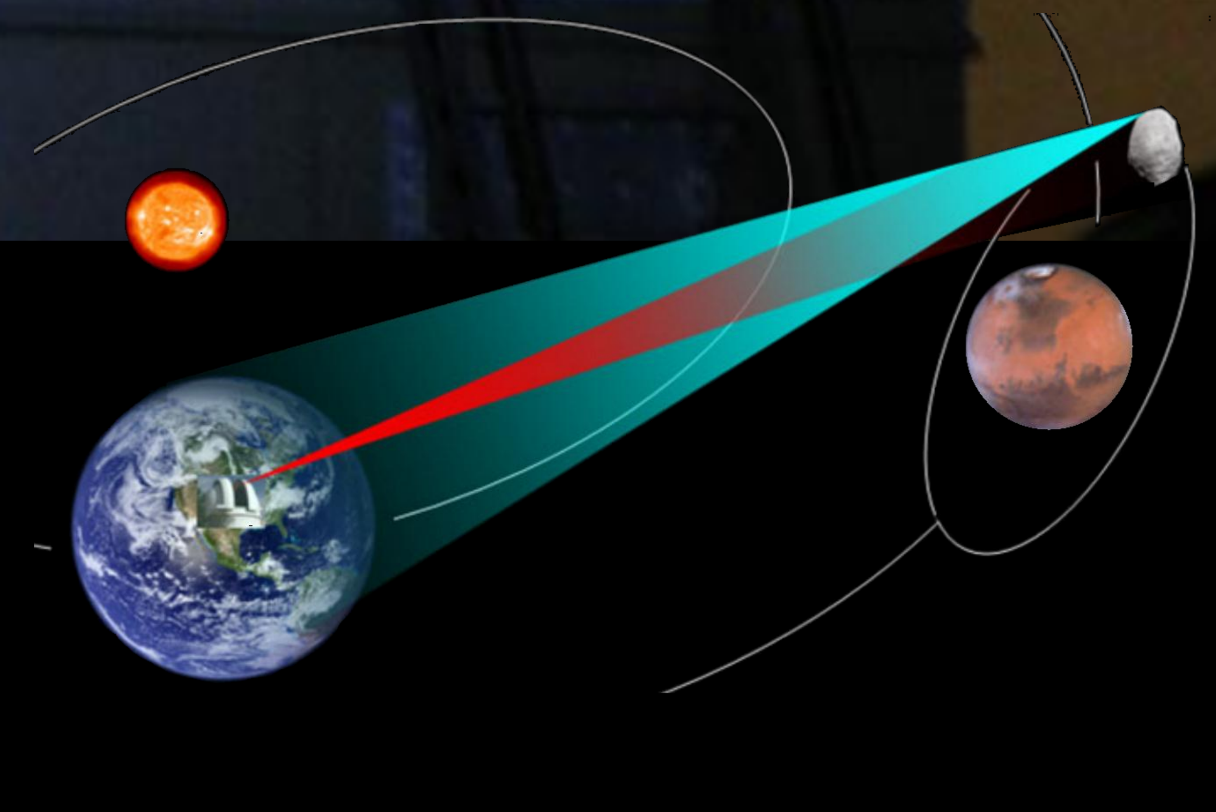

Figure 3: Schematic representation of the Phobos Laser Ranging mission concept, adapted from (Turyshev et al., 2012

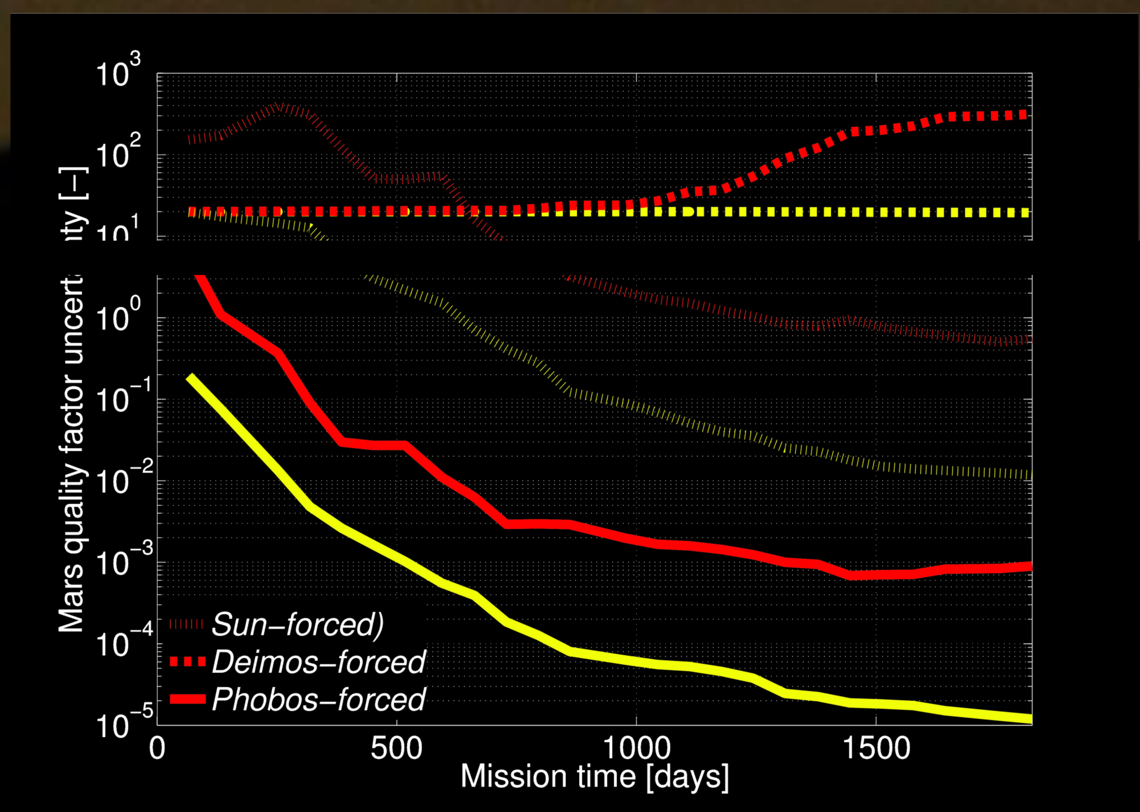

Figure 4: Estimation result for Mars quality factors at forcing frequencies. Blue: without systematic errors. Red: with 5-mm consider errors.

The following are key results from the science parameter estimation, taking 5-mm consider parameter uncertainty:

- Short period librations can be estimated at the 10^{-5}-10^{-7} degree level (see Fig. 2 for several representative terms of longitude librations).
- Estimation of Mars quality factors at forcing frequencies of Phobos ($<10^{-3}$) and Sun (<0.5) synodic periods (but not Deimos, see Fig. 4).
- Strong constraints ($<10^{-4}$) on Mars degree 2 and 3 Love numbers.

However, improved Mars interior and atmosphere models will be needed to take full advantage of the data. Combination with Mars seismic and rotation data, for instance from the *Insight* mission, will provide further constraints on Mars interior.

Conclusions & outlook

We have set up a general mission simulation framework and applied it for assessing the potential of a Phobos laser lander mission. Our simulations indicate substantial return for Phobos and Mars science. However, uncertainties due to systematic observation errors and ground station positions currently dominate the error due to 1-mm observation noise.

Future work will focus on linking the system hardware to the observation and noise models to provide a realistic, mission geometry- and system-dependent analyses of estimation uncertainties.

Publications

- D.Dirkx, L.L.A.Vermeersen, R.Noomen, P.N.A.M. Visser (2014), "Phobos Laser Ranging: Numerical Geodesy experiments for Martian System Science", Planetary and Space Science (Article in Press)
- D.Dirkx, R. Noomen, I. Prochazka, S. Bauer, L.L.A. Vermeersen (2014), "Influence of atmospheric turbulence on planetary transceiver laser ranging", Advances in Space Research (Submitted)