Orbital Evolution of the Mars-Phobos Tidal System Amirhossein Bagheri[1], Amir Khan[1], Michael Efroimsky[2], Domenico Giardini[1], [1]Institute of Geophysics, ETH Zurich, Zurich, Switzerland, [2]U.S. Naval Observatory, Washington, D. C., USA

Introduction: NASA's InSight spacecraft successfully landed on Mars in November to place a set of instruments on the planet. The mission is planned to provide data about seismic activity, geodetic properties, and heat transport in Mars. In this context, we aim to study the tidal evolution of the Mars-Phobos system using constraints on the interior structure obtained from geodetic data.

Tidal dissipation due to viscoelastic deformation in Mars' mantle results in momentum exchange between the orbit of the satellites, Phobos and Deimos, and spin of the planet and consequent evolution of the orbital characteristics. Studying tidal dissipation and orbital evolution helps to understand the processes that the system has undergone during its history and also constrain the future processes. Phobos is within the synchronous radius and spiraling inwards in contrary to Deimos which is outside of the synchronous radius and is gradually getting away from Mars.

In this study, we consider the evolution of the orbital properties by exploiting the constraints on Mars' interior structure and dissipation characteristics obtained from inversion of geodetic data in solution of the orbital evolution problem.

Modeling Mars Interior Structure. We parameterize our model based on temperature, grain-size, power-dependence of attenuation, composition, crustal thickness, core size, and state. (Khan et al. 2018) We use several rheological models, i.e. Andrade, extended Burgers, Sundberg-Cooper (2010), and power-law to compute the dissipative properties within Mars and calculate the global quality factor. Our forward model, produces profiles of density, elastic properties, and attenuation from the model parameters and computes the geodetic observables. The forward model has the option of using each of the aforementioned rheological models to compute the attenuation profiles.

Inversion. We invert the existing geodetic data for tidal Love number and quality factor (at the synodic period of Phobos' orbit), mean mass, and mean moment of inertia for the model parameters. We use a probabilistic approach and Metropolis algorithm to constrain the model parameters. Figure 1 shows the density, seismic wave velocity, and attenuation obtained from inversion. Moreover, based on the constraints we obtain for the model viscoelastic model parameters, we can compute the tidal response (Love number and quality factor) at other periods which Phobos and Deimos would have during the evolution process either back in their history or later in the future. Figure 2, shows the
variations of Love numbers and global attenuation factor obtained at three different periods.

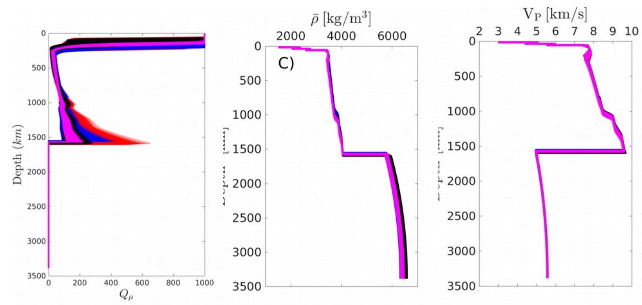

Figure 1. Profiles of density, P-wave velocity, and attenuation obtained from inversion based on different rheological models.

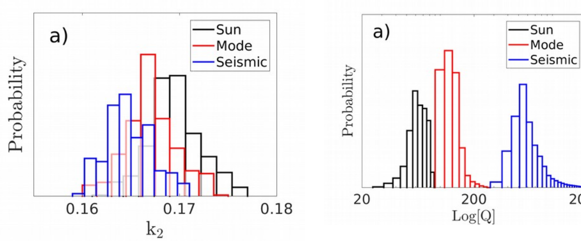

Figure 2. Tidal Love number and quality factor at the periods: 12 hr (sun), 1 hr (Mode), 1 sec (seismic) by using Andrade's model.

Evolution of Orbital Properties. We divide our study of the orbital evolution into two parts. In the first part, we consider the variations of the orbital properties from the present back to the point back in time when Phobos was at the synchronous radius of Mars. We compute the duration of this interval and study the interrelated variations of eccentricity of the orbit, semi-major axis of Phobos and the changes in the spin period of Mars. For this purpose we numerically solve the three coupled differential equations following Heller et al. [2011].

The preliminary results are presented here. Figure 3 shows the evolution of the semi-major axis of Phobos and Deimos and the variations of spin period of Mars associated with the dissipation due to Phobos. The results are calculated based on Andrade's rheological model.

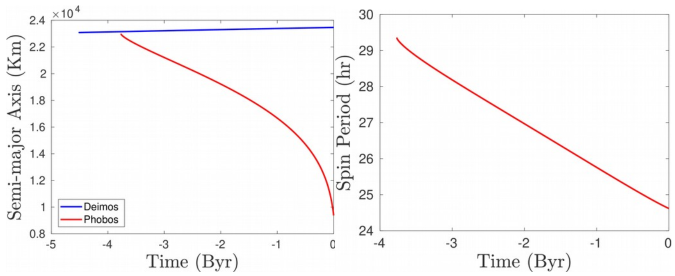

Figure 3. Variations of semi-major axis of Phobos and Deimos, and spin period of Mars due to dissipation associated with Phobos only (right).

The plot indicates that the variations of the spin period of Mars (duration of Martian days) due to dissipation's associated with Phobos is not negligible.

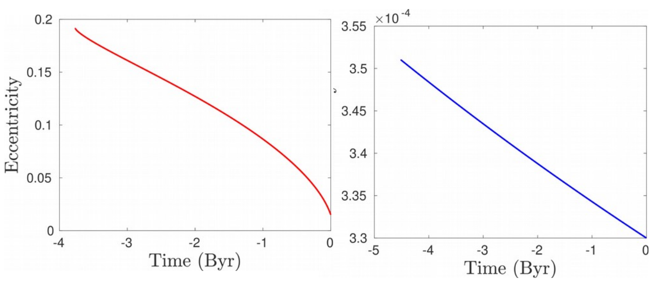

Figure 4. Variations of eccentricity with time for Deimos (left) and Phobos (right)

Figure 4 shows the variations of eccentricity of the orbit with time for the two satellites.

In the second part, we focus on the orbital evolution of the Mars-Phobos system from the present day until Phobos possibly reaches Mars' surface, i.e. we compute the remaining lifetime of Phobos. Since the higher degree effects become more important as the satellite gets closer to the planet, we account, in addition to the second degree, for the third degree effects in our calculations of the remaining lifetime. The dissipative properties of Mars change during the orbital evolution. We account for these changes by using the aforementioned rheological models and the constraints obtained for the frequency dependence of dissipation rate.

Figure 5 shows the variations of the semi-major of Phobos axis with time.

The figures imply that the remaining lifetime of Phobos based on the contributions by k_2 and k_3 is almost 34 million years.

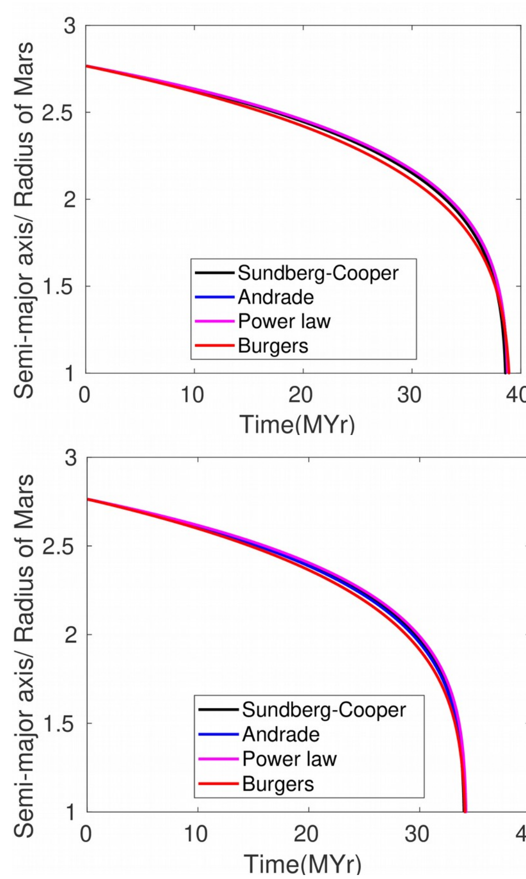

Figure 5. Evolution of semi-major axis with time computed based on different rheological models (up: k_2 contribution only, Bottom k_2 and k_3 contribution)

The figure also reveal that the choice of the different rheological model does not considerably affect the remaining lifetime of Phobos, since the variations of the period from the present until the time Phobos supposedly crashes on Mars is not very high. Different rheological models can make a more pronounced difference when considering the history of the orbital system where the variations of the period is much higher. This is due to the fact that the synodic period becomes much higher close to spin-orbit resonance. [Efroimsky, 2012]. This problem is already under consideration by the Authors.

References.

[1] R. Heller et al. (2011) Astron. Astrophys. 528, A27 [2] A. Khan et al. (2018) JGR: Planets, 123 [3] Sundberg, M., and R. Cooper (2010), Philosophical Magazine, 90 (20), 2817–2840 [4] [5] M. Efroimsky, (2012) Celest Mech Dyn Astr 112:283–330