TIDAL CONSTRAINTS ON THE MARTIAN INTERIOR. L. Pou1, F. Nimmo1, A. Rovoldini2, A. Khan3,4, A. Bagnedi, T. Gray3, H. Samuel3, P. Lognonné3, A.-C. Plesa4, T. Gudkova1, D. Giardini2 1University of California Santa Cruz, Dept. Earth and Planetary Sciences, 1158 High Street, CA 95064, United States (pou@ucsc.edu) 2Royal Observatory of Belgium, Avenue Circulaire 3, B-1180 Brussels, Belgium 3Institute of Geophysics, ETH Zürich, Sonneggstrasse 5, 8092 Zürich, Switzerland 4Physik-Institut, University of Zurich, Zurich, Switzerland 5Institut de Physique du Globe de Paris, Université Paris Diderot-Sorbonne Paris Cité, 35 rue Hélène Brion - Case 7071, Lamarck A, 75205 Paris Cedex 13, France 6Planetary Physics, Institute of Planetary Research, German Aerospace Center (DLR), Rutherfordstraße 2, Berlin 12489, Germany 7Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, Moscow 123242, Russia

\[ s = \frac{3 m^*}{2 m} n^2 \left( \frac{k_{2200}}{Q_{2200}} \right) \left( \frac{r}{a^*} \right)^5 \]

\[ + \frac{3}{8} \left( \frac{k_{3110}}{Q_{3110}} \right) \left( \frac{r}{a^*} \right)^7 \]

\[ + 5 \left( \frac{k_{24210}}{Q_{24210}} \right) \left( \frac{r}{a^*} \right)^9 \]

\[ + \frac{15}{128} \left( \frac{k_{5510}}{Q_{5510}} \right) \left( \frac{r}{a^*} \right)^{11} \]

where \( m^* \) and \( m \) are the mass of Phobos and Mars, respectively, \( r \) is the radius of Mars, \( a^* \) is the semimajor axis of Phobos, and \( k_{impq} \) and \( Q_{impq} \) are the Love number and the tidal quality factor for the Phobos tide of degree \( l \) and order \( m \), respectively. The Love numbers and tidal quality factor are frequency dependent and must be calculated for \( T_{1m} = T_1/m \) where \( T_1 = 11h 06min \) is the synodic period of Phobos.

Martiian models: We study 5 families of models: the FN models based on [7], the AB models based on [8,9], the HS models based on [10], the TG models based on [11], and the AR models based on [12-15]. Except for the AB models constructed by inverting geophysical parameters to match the data, we adjust several parameters (core size, temperature...). to match Table 1. Core size estimates are summarized in Fig. 1.

<table>
<thead>
<tr>
<th>Tidal parameter</th>
<th>Values</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Love number ( k^2 ) of Mars</td>
<td>0.174 ± 0.08</td>
<td>[3]</td>
</tr>
<tr>
<td>Secular acceleration ( s ) of Phobos (mdeg.yr(^{-2}))</td>
<td>1.273 ± 0.003</td>
<td>[5]</td>
</tr>
</tbody>
</table>

Table 1: Tidal constraints to be satisfied by all models.

Derivation of the secular acceleration of Phobos:

Because of the proximity of Phobos to Mars, higher-degree tides must be considered in the calculation of the secular acceleration \( s \). Based on the works of [6], given the negligible inclination and eccentricity of Phobos and our focus on the equatorial tidal bulge of Mars, the expression for the secular acceleration is (1):

**Temperature and lithosphere thickness:** We compare our temperature profiles with estimations of the lithosphere thickness. To fit the elastic thickness of...
the lithosphere $T_e$ at the poles from [17-18], an average $T_e$ of 275$\pm$10 km is needed, corresponding to the green box in Fig. 2. This is compatible with seismic observations of the upper mantle in [19] and geotherms in [20] and favor models assuming colder mantle temperatures.

Synergy with seismic measurements: From the measurements of $k_2^2$ and $s$, the tidal bulk attenuation of Mars $Q_{2200}$ is strongly constrained with Eq. (1) at the frequencies of the Phobos tides (between 11.1hr and 2.2hr). However, due to the different rheology models and temperature profiles, the models yield distinct $Q_\mu$ profiles at seismic frequencies, as illustrated in Fig. 3. Measurements of the seismic shear attenuation in the deepest part of the mantle with an accuracy better than $\pm$ 500 would be able to distinguish between models.

Figure 2: Temperature profiles for our models, compared to the inverted geotherms from [19] and the elastic thickness of the lithosphere estimations from [17-18] represented by the green box. Colder mantle temperatures are favored.

Figure 3: Shear attenuation $Q_\mu$ profiles at 1s for our models. An accuracy better than $\pm$ 500 on the attenuation in the lower mantle of Mars would be sufficient to distinguish between our models.

Chandler Wobble: Predictions of the Chandler Wobble period are shown in Fig. 4 for our models, compared to the measurements from [3]. While all our models match $k_2^2$ for the Solar tide, they do not match $P_{CW}$ at 206.9 days. However, while $P_{CW}$ is sensitive to the frequency dependency $\alpha$ of $Q_\mu$, there are also other influences at play. Fig. 4 therefore only indicates likely values rather than a direct determination of $\alpha$.

![Figure 4](image)

Figure 4: Comparison of the $k_2^2$ and $P_{CW}$ values (left and right, respectively) for our models. Left areas are based on Table 1, while the right orange area is from the $P_{CW}$ estimation of [3].

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References: