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Constraining the thermal history of Mars using satellite orbital evolution

henri samuel (1), Philippe Lognone (2), Mark Panning (3,4)

(1) CNRS -IPGP, Planetary and Space Sciences, France (samuel@ipgp.fr), (2) Paris Diderot University- IPGP, Planetary and Space Sciences, France , (3) Jet Propulsion Laboratory, USA , (4) California Institute of Technology, USA

While the present-day surface of Mars is relatively well documented and characterized, the details of its evolution and deep internal structure remain, in comparison, poorly known. Combining the data collected from space missions with geophysical and geodynamic considerations allows the thermal evolution of Mars' silicate and metallic envelopes to be constrained. However, the limited amount of currently available data and the interplay between several key physical quantities (e.g., temperature, composition, and rheology) requires strong assumptions to be made concerning the values of several of these governing parameters to infer the planet's thermal history. The upcoming InSight mission to Mars is expected to significantly enhance our knowledge of its interior, in particular, by providing heat flow measurements and seismic recordings. The mission will also allow estimates of Mars' Love number, which influences the orbital evolution of its satellites, Phobos and Deimos, to be refined. A main difference between these two orbiting objects is that the former spirals towards the planet, while the latter, being located beyond the synchronous orbit, gradually moves away from it. These orbital evolutions are also governed by Mars' tidal dissipation. Similar to the thermally activated processes of seismic wave attenuation in planetary bodies, Mars' tidal dissipation is related to its thermal state.

Therefore, to further constrain the thermal history of Mars, we have focused on this particular aspect. We modeled a series of thermal evolutions of Mars' core and mantle, to which we coupled the orbital evolutions of Phobos and Deimos. We systematically varied over large plausible ranges the main governing parameters for Mars' thermal evolution, i.e., the mantle viscosity and its activation energy, the initial temperature of the mantle and the core, and the crustal enrichment in radioactive heat-producing elements. The resulting orbital evolutions allow bounds to be placed on the aforementioned governing parameters. In the case of Phobos, its existence today requires that (i) it was put in orbit after the formation of Mars, (ii) in a way compatible with its capture. The first condition yields a maximum capture age of 4.5 Byrs. Assuming aerocapture processes, the second condition implies the presence of a dense atmosphere, which likely disappeared four billion years ago. This leads a time window for Phobos' capture of 4.5-4 Byrs before present.

We derived simple scalings to describe the trade-offs between physical parameters, which can be used to discriminate between thermal evolution models.

Such thermal–orbital constraints provide an independent and alternative way to decipher the dynamic history of Mars and would allow for an improved interpretation of the expected data from upcoming space missions.