

Mars' Split Personality: Explaining the Crustal Dichotomy and Other Characteristics Through Large-Scale Impact Simulations Coupled to Long-Term Thermochemical Models

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Abstract

We present initial results of high resolution (10^5 – 10^7), smoothed-particle hydrodynamic (SPH) simulations that are being used to study the effect that a giant impact would have had on Mars not long after the planet's formation, with a particular focus upon whether this could explain the martian crustal dichotomy or the martian moons Phobos and Deimos.

1. Introduction

1.1. The Martian Dichotomy

Almost 50 years ago, NASA's Mariner 9 space probe performed the first complete orbit of a planet other than Earth. This was around our smaller celestial neighbour – Mars. Along the way, this spacecraft obtained images of approximately 85% of the planet's surface in unprecedented detail, revealing a stark contrast between the northern and southern hemispheres now known as the martian crustal dichotomy. This moniker predominantly refers to the 4.8 km difference in elevation between the southern hemisphere and an apparent basin covering roughly 42% of the north. Other associated features include a higher density of volcanoes and visible impact craters in the south relative to the north.

Some studies have attempted to explain these properties through endogenic means; namely via degree-1 mantle convection studied using large-scale thermochemical models (e.g. Keller and Tackley, 2009). Others have taken the exogenic route, proposing that a giant impact early in Mars' history caused the excavation of a large mass of material from the northern hemisphere, thus giving rise to the observed dichotomy (e.g. Marinova et al., 2008). Given that such collisions are expected to be very common in the final stages of terrestrial planetary accretion, this

approach is highly feasible. The latter studies have, however, generally ignored any long-term geodynamical consequences on the martian interior that such an event may cause.

We use an approach that aims to couple these two hypotheses into a hybrid exogenic-endogenic scenario, whereby a giant impact triggered a localised magma ocean and subsequent superplume in the southern hemisphere. This consists of two separate components which are coupled in a hybrid scheme (Golabek et al., 2018): smoothed-particle hydrodynamic (SPH) simulations of the initial impact, and the subsequent long-term thermochemical evolution of the interior of Mars over the following 4.5 Gyr to the present day. The parameter-space of these models will be constrained by the upcoming results from the Insight lander on Mars.

1.2. Phobos and Deimos

Another interesting feature of Mars is that of its two miniature moons, Phobos and Deimos. With a combined mass of only $M_{PD} = 2 \times 10^{-8} M_M$, where $M_M = 6.4 \times 10^{26}$ g is the mass of Mars, and highly cratered, asymmetrical appearances, many previous studies assumed these objects to be captured objects, supported further by their similar reflectance spectra to those of D-type asteroids (Murchie et al., 2015, and references therein). However, their highly circular orbits (eccentricities of less than 0.02) make such an origin very difficult to reconcile, even when considering the additional tidal dissipation due to their high estimated porosities.

By contrast, such an orbital configuration is expected from the formation of moons in a debris disk around Mars – a natural consequence of a giant impact such as the possible dichotomy-forming event (Canup and Salmon, 2018). Furthermore, the high porosities

of these bodies are expected in such a scenario. This hypothesis is also being studied through the aforementioned SPH simulations, initially via a study into the effects that the material strength and numerical resolution may have on the resulting disk mass.

2. Method

Through SPH simulations, various impact angles, velocities and impactor radii (generally on the $\approx 1000\text{km}$ scale) are being explored, using a range of different resolutions (10^5 - 10^7 SPH particles). In addition, the effects of shear strength and plasticity (via Drucker-Prager-like yield criterion) are being studied, as such effects have been shown to be significant on the scales concerned in this study (Emsenhuber et al., 2018). Moreover, the sophisticated equation of state ANEOS is being used along with a Mars-specific solidus (Duncan et al., 2018) to accurately calculate the parameter-space in which such solid characteristics must be considered. In all of these studies, both Mars and the impactor are treated as differentiated bodies. An example result of one of these simulations can be seen in Figure 1.

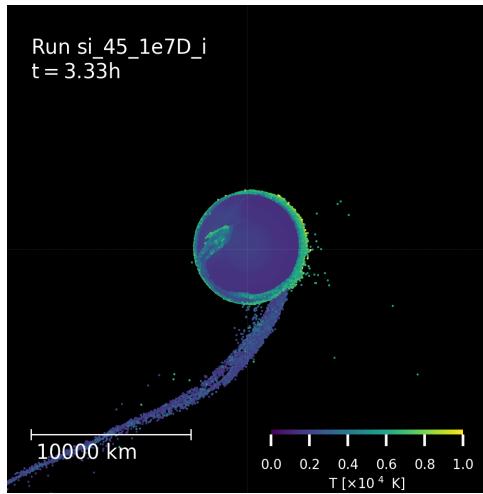


Figure 1: The resulting temperature field of a Mars-like body from a 10^7 particle SPH simulation 3.33hr after an impact with a $\approx 1000\text{km}$ radius impactor at a 45% impact angle.

3. Preliminary Results

The initial results of this study have displayed significant differences when varying the resolution of the numerical model, particularly when studying the impact-generated disk. This is an expected result, as the disk masses produced in this scenario are sufficiently low relative to their parent body ($\approx 1 \times 10^{-4} M_M$) such that they straddle the current resolvable limit due to computational restrictions. An important aim of this study is to therefore quantify a lower-limit of resolution for which a disk can be considered to be sufficiently resolved.

In addition, the effects of material strength have been found to be non-negligible, in contrast to previous beliefs that such aspects can be ignored on the length-scales involved in planetary collisions.

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