Mars' Split Personality: Explaining the Crustal Dichotomy and Other Characteristics Through Large-Scale Impact Simulations Coupled to Long-Term Thermochemical Models. Harry Ballantyne[1], Martin Jutzi[1], Gregor Golabek[2], Kar Wai Cheng[3] and Paul Tackley[3], [1]Universität Bern, Space Research & Planetary Sciences (WP), Bern, Switzerland, [2]Bayerisches Geoinstitut, Germany, [3]ETH Zürich, Institute of Geophysics, Zürich, Switzerland.

Introduction: *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 [1]. 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 [2]. 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 localized magma ocean and subsequent superplume in the southern hemisphere. This consists of two separate components which are coupled in a hybrid scheme [3]: 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.

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 crated, 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 [4]. 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 [5, 6]. 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.

Method: Through SPH simulations, various impact angles, velocities and impactor radii (generally on the ≈1000km 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 a Drucker-Prager-like yield criterion) are being studied, as such effects have been shown to be significant on the scales concerned in this study [7]. Moreover, the sophisticated equation of state ANEOS is being used along with a Mars-specific solidus [8] 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.

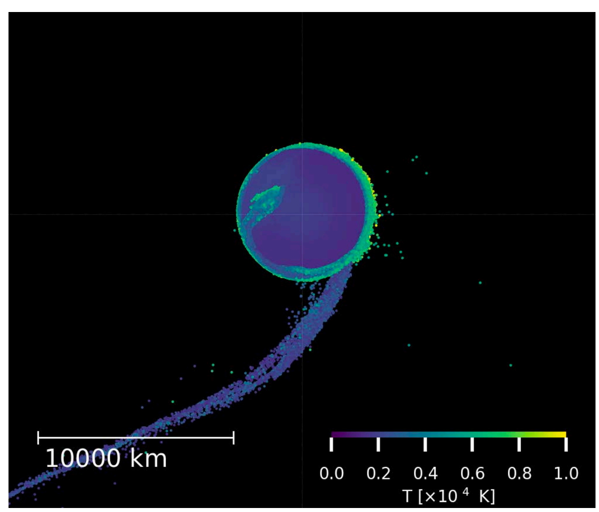

Figure 1: The resulting temperature field of a Mars-like body from a 10^7 particle SPH simulation 3.33hr after an impact with a ≈1000km radius impactor at a 45° impact angle.

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 ($\approx 1\times10^{-4}$ 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.

References: [1] Keller, T. and Tackley, P. J. (2009) *Icarus, 202(2):429–443*. [2] Marinova, M. M., Aharonson, O., and Asphaug, E. (2008) *Nature, 453(7199):1216–1219.* [3] Golabek, G. J., Emsenhuber, A., Jutzi, M., Asphaug, E. I., and Gerya, T. V. (2018) *Icarus, 301:235–246.* [4] Murchie, S. L., Thomas, P. C., Rivkin, A. S., and Chabot, N. L. (2015) *Asteroids IV.* [5] Canup, R. and Salmon, J. (2018) *Science Advances, 4(4).* [6] Hyodo, R., Genda, H., Charnoz, S., & Rosenblatt, P. (2017) *The Astrophysical Journal, 845(2), 125.* [7] Emsenhuber, A., Jutzi, M., and Benz, W. (2018). *Icarus, 301:247–257.* [8] Duncan, M. S., Schmerr, N. C., Bertka, C. M., and Fei, Y. (2018) *Geophysical Research Letters, pages 211–220.*