HEATING OF THE MARTIAN INTERIOR DUE TO GIANT IMPACTS: REVISITED. J. H. Roberts[1],
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Introduction: While Mars currently has no global magnetic field, widespread crustal magnetism [1] suggests that such a field existed in the past, and implies that a dynamo once operated on Mars [2]. The absence of magnetization in the youngest large impact basins suggest that the dynamo stopped by the late Noachian, presumably because the heat flow became unfavorable to core convection [3]. Within a ~100 Ma period, a series of six supergiant impacts occurred (forming basins of diameter D > 2500 km) [4,5]. The age of Utopia, the youngest and largest supergiant basin, coincides with the disappearance of the global magnetic field [6].

Numerical modeling studies [7] suggest that giant impacts can significantly heat the Martian mantle, and may have profound consequences for the thermal evolution of the planet. Further investigation [8] finds that the supergiant impacts can significantly reduce the core mantle boundary (CMB) heat flow by up to 40%, depending on model parameters. Simulations of core dynamos [9] show that a drop in heat flow of ~1% is sufficient to shut down a subcritical dynamo, which will not restart when the previous heat flow is re-established. Thus, although the drop in core heat flow due to impacts is temporary [8], the effect on the magnetic field may be permanent.

Such modeling results naturally depend on several assumptions and model parameter, such as crater scaling [10] and thermomechanical parameters [6,11], many of which are poorly known. Here I revisit two aspects of an earlier modeling study [8] in order to better understand the mechanism by which impacts can affect the thermal evolution of Mars.

Core Heat Flow: A planet's magnetic field is produced by vigorous convection in an electrically conducting fluid, i.e., a fluid iron core. Such convection is primarily driven by core cooling as it loses heat to the colder mantle above. Due to its higher viscosity, the mantle convects much more sluggishly than the core; thus core cooling is controlled by the thermal state of the mantle. To first order, if the mantle is heated externally (say by an impact), it cannot cool the core as efficiently, and in extreme cases may reverse the direction of heat flow across the CMB. This description, while correct on a global scale, somewhat oversimplifies the process.

The net CMB heat flow is the sum of an advective component arising from the vertical movement of warm buoyant material, and a diffusive component due to the temperature gradient. Upon a temperature increase (e.g. from an impact), these two components change in opposite directions. The increase in temperature beneath the impact site reduces the differential between core and mantle, thereby lowering the diffusive heat flux. However, the temperature rise increases buoyancy, and thus vertical velocity of material, causing a rise in the advective heat flux. In the models of [8], the diffusive heat flux wins out on a global scale and the total heat flow is reduced following a giant impact.

The temperature increase due to an impact decays sharply with distance from the impact site [6,11]. This results in an increase of ~30 K at the CMB directly beneath the impact, but an increase of only a few K farther away. Figure 1 shows the spatial distribution of temperature, radial velocity, and net CMB heat flux immediately after a Utopia-sized impact. There is substantial lateral variation in all three plots.

Shock Model: A giant impact creates a shock wave which propagates outward from an isobaric core centered on the impact site. Adiabatic re-expansion of material behind the shock front results in heating [7]. The models of [8] parameterize the impact heating as an instantaneous increase in temperature using the ordinary shock model of [7]. However, the ordinary shock model does not account for the lithospheric pressure [Arkani-Hamed, J. (2009), pers. comm.]. For this we use the foundering shock model, in which the lithospheric pressure is subtracted from the shock pressure before the temperature increase is computed. Thus, the impact heating is severely reduced at depth. As in [8], mantle convection models were run in which heating from the giant impacts as determined from the foundering shock model was imposed at times specified by [4]. Figure 2 shows the difference in CMB heat flow between models with and without impacts for both ordinary and foundering shocks. The CMB heat flow anomaly is much weaker for

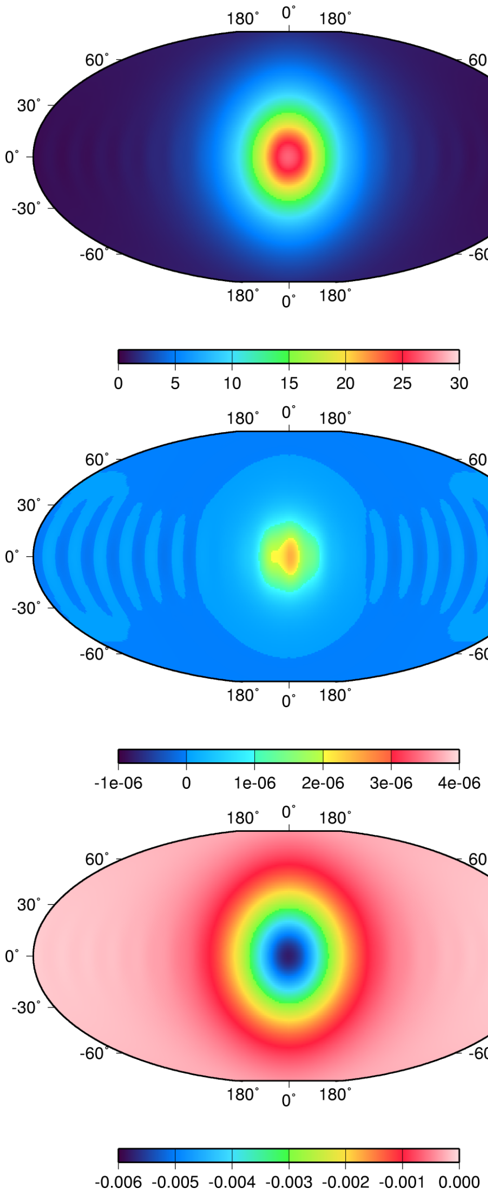

Figure 1: Change in temperature (K, top), radial velocity (m/s, middle), and net heat flux (W/m^2, bottom) at the CMB due to a Utopia-sized impact at (0,0), using the ordinary shock model of [6].

foundering shocks than for ordinary shocks, and in some cases, the anomaly is even positive. A decrease in CMB heat flow of up to ~2% flow is observed for the foundering shock case. This is still sufficient to shut down a subcritical dynamo, but is more difficult than found previously [8].

Discussion: In Figure 1, the radial velocity change is positive only under the impact site, and must be negative elsewhere to satisfy conservation laws. Thus, the advective heat flux only increases in a small

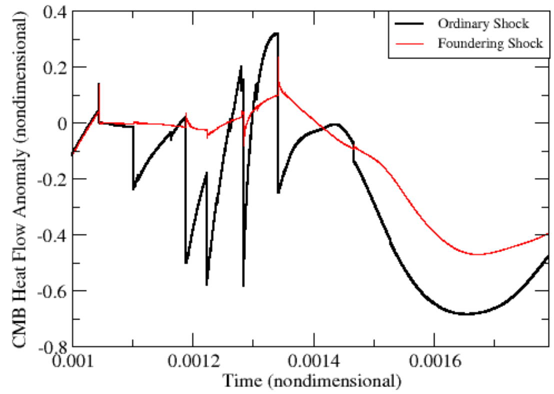

Figure 2: Difference in CMB heat flow between models with and without giant impacts for ordinary and foundering shock models. Rapid changes in heat flow denote times of giant impacts.

region, while the diffusive heat flux decreases everywhere. In the ordinary shock heating models of [8], the net CMB heat flux drops. In Figure 2, the heat flow *increases* after some impacts, suggesting that the advective component is stronger than the diffusive in these cases. This is likely because heating is concentrated at shallower depths when foundering shocks are used, and decreases the change in diffusive heat flux at the CMB. The shallower heated material is still buoyant and rises. Deeper material may also be drawn upwards, potentially causing a rise in the advective CMB heat flux.

Additional investigation is needed to determine the conditions under which a net increase or decrease in core cooling is expected due to impacts, and the applicability of the various shock models to impact heating on Mars. The effect of strong lateral variations in heat flow also needs to be explored further. Such heterogeneity may alter the supercritical and subcritical Rayleigh numbers for dynamo activity [9].

References: [1] Acuña et al. (2001) *JGR 106*, 23,403-23,417. [2] Arkani-Hamed, J. and D. Boutin (2004) *JGR 109*, E03011. [3] Nimmo, F, and D. J. Stevenson (2000) *JGR 105*, 11,969-11,979. [4] Frey, H. V. (2008) *GRL 35,* L13203. [5] Frey, H. V. (2009) *LPSC* 40, 1123. [6] Lillis, R. J. et al. (2008) *GRL 35*, L14203. [7] Watters, W.A. et al. (2009). *JGR* 114, E02001. [8] Roberts, J.H. et al. (2009) *JGR* 114, E04009. [9] Kuang, W. et al. (2008) *GRL 35*, L14204. [10] McKinnon, W. B., et al. (2003), in *Impact Cratering: Bridging the Gap Between Modeling and Observations*, 8047. [11] Monteux, J., et al. (2007) *GRL 34*, L24201.