A TRANSIENT DYNAMO ON VESTA?. James H. Roberts, Andy S. Rivkin, Nancy L. Chabot, *Johns Hopkins University Applied Physics Lab, Laurel, MD 20723 (James.Roberts@jhuapl.edu)*.

Introduction: 4 Vesta is the second largest asteroid in the solar system. Vesta is characterized by a large topographic depression at the south pole [1], believed to be a giant impact basin [2]. It is thought that the Vesta family of asteroids are products of the collision that formed this Australis basin, and that the Howard-Eucrite-Diogenite (HED) meteorites represent pieces of Vesta's crust [3-5], ejected during this impact. Vesta is thus thought to be a differentiated body [4,6] with a Fe-Ni core [7], an olivine-rich silicate mantle, and an outer crust.

Vesta is a small body and has cooled over the age of the solar system. The iron core is likely to be frozen and incapable of maintaining dynamo activity today. However, the fact that Vesta is differentiated suggests that it was quite warm initially [6]. Vesta may have undergone rapid cooling, and exhibited short-lived dynamo activity. Remanent magnetization has been measured on some HED meteorites [8], but the origin of the magnetization is not clear. Only the oldest such meteorites could have recorded an early dynamo with a lifetime less than 100 My [9].

The survival of the smaller (10 km) fragments in the Vesta family suggest that the Australis impact must be relatively recent, within the last Gy [10]. Large impacts can introduce a substantial amount of heat into the interior of planetary bodies [11]. We investigate the idea that the Australis impact may have remelted the core, and that the subsequent cooling could have driven a recent transient dynamo.

Thermal Evolution: We model Vesta as a differentiated body of mean radius 290 km with a core of radius 123 km [10]. Because the impact basin is at the south pole, Vesta is largely axisymmetric. Therefore, we model the early thermal evolution using the 2D axisymmetric finite-element code Citcom [12]. We apply temperature boundary conditions at the surface and core-mantle boundary (CMB). The surface temperature is taken to be 155 K. The CMB temperature is initially 1255K. The mantle is heated from within by radioactive decay [13]. Citcom is primarily used to model thermal convection; however the small size and low gravity on Vesta make this unlikely, except possibly early on when the mantle was quite warm, or shortly after the basin-forming impact. Thus, the cooling of the interior proceeds primarily through conduction, which can be computed analytically.

An Early Dynamo: Figure 1 shows the background heat flux evolution for a model Vesta with a convective initial temperature profile. Vesta's small size and low gravity renders mantle convection unsustainable, and the heat flux rapidly evolves to a conductive state. (The difference in surface and CMB values can be attributed to radioactive heating.) It is not clear in this case that the CMB heat flux ever is high enough to drive a dynamo. Even early when the mantle is fluid, the mantle is losing its own heat and not cooling the core efficiently. Later, heat from the core must diffuse through the mantle, and this is slow.

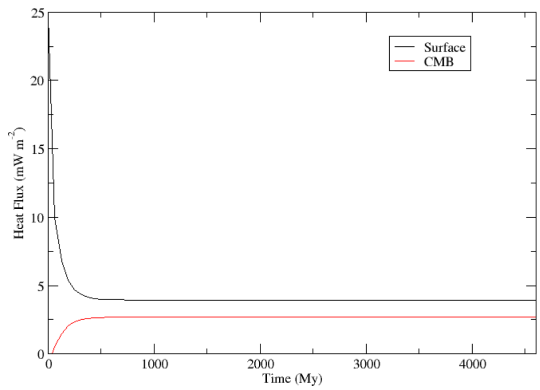

Figure 1: Evolution of surface (black) and CMB (red) heat flux from Vesta.

Impact Heating: While Vesta has long since lost its accretionary heat, the impact that formed the Australis basin may have delivered substantial heat to the interior much more recently. We therefore investigate the possibility that such an impact may have initiated more recent, transient dynamo activity.

We use scaling relations [14-16] to obtain the impactor size, $R_p = 40$ km from the observed basin size $D_b = 450$ km, assuming an impactor velocity of 5.4 km/s [16]. A significant fraction of the impactor's kinetic energy will be converted to thermal energy, raising the temperature of the surrounding mantle. The interior is heated by a shock wave emanatimg from the impact location. Heating is uniform within an isobaric core, which scales with the impactor size and decays rapidly outside this region [11]. We parameterize the impact heating as a temperature perturbation in the mantle and core, which is a function of the shock pressure [17].

The timing of this impact is not well known. However, since the initial heat from accretion and differentiation is lost so quickly, and Vesta is not dynamically active, the background thermal profile does not change dramatically with time. Thus, the precise timing does not have a significant effect on the post-impact evolution of Vesta. Following the shock heating method [11,17], we simulate the impact heating as an instantaneous temperature increase in the interior. We assume an initially conductive temperature profile in the mantle and an initially isothermal core. Figure 2 shows the 2D temperature structure immediately before and after the impact that formed the Australis basin. Because the impact at Vesta is expected to be relatively slow [16], the shock pressure decays relatively weakly with distance. While the impact heating is strongest near the site of the impact, even distant regions of the asteroid are heated by $\sim$300 K. Thus, the entire core and mantle receive significant heating.

Counterintuitively, an impact may raise the core temperature more than the mantle temperature. This is largely due to

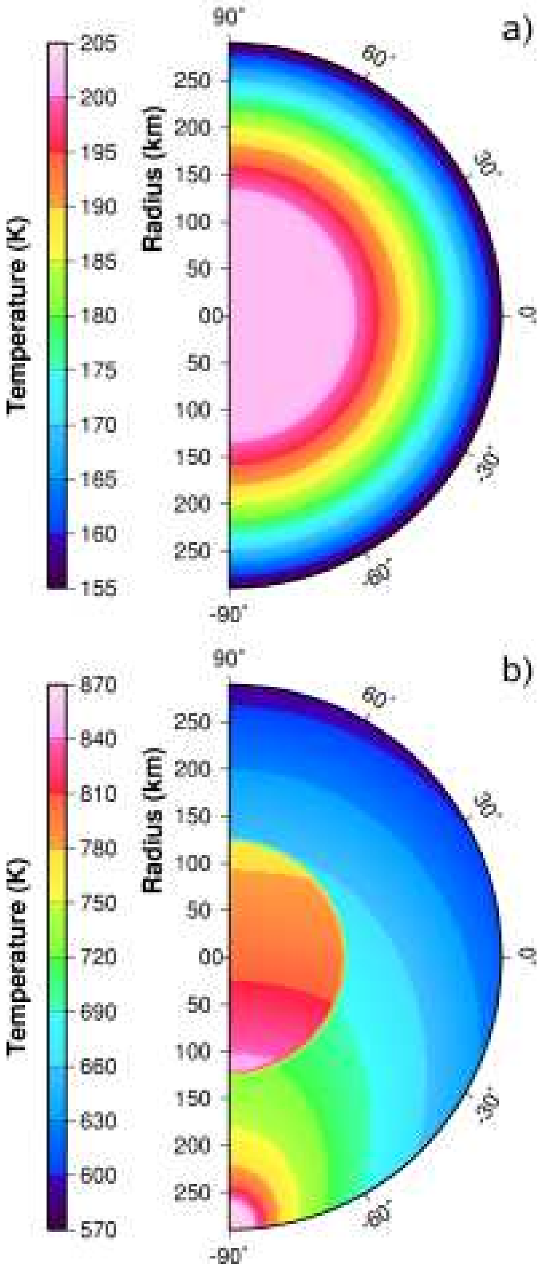

Figure 2: 2D temperature profile immediately before (a) and after (b) the Australis impact.

the lower specific heat in the core. However, the temperature does not increase enough to melt the core and thus, no dynamo activity can be initiated. Somewhat higher temperatures can be achieved due to higher levels of radioactivity in the past. Nevertheless, the core temperature does not reach the melting point of even the Fe-S eutectic composition (Figure 2b).

Discussion: Our results suggest that a dynamo on Vesta could only have operated very early on, when the interior was still warm from accretion and differentiation. Our thermal models show that the mantle would have reached a conductive steady state within a few hundred million years. Even in these early stages, sustaining a dynamo is difficult. The early mantle would have been so warm that the CMB heat flux was unfavorable to dynamo activity. However, the early heat flux is sensitive to poorly known initial conditions, and thus we cannot rule out an early dynamo at this stage.

We find that a transient dynamo cannot be initiated using heating from the Austalis impact. While the stronger temperature increase in the core produces a favorable heat flux condition, there is insufficient energy to melt the core. More energetic projectiles than the one that formed the Australis basin would disrupt Vesta before they became sufficiently energetic to melt the core.

Thus, we conclude that no dynamo could have operated on Vesta more recently than about 4 Gya. The difficulty generating a dynamo on Vesta implies that asteroid dynamos are not common. Vesta the largest known asteroid except for Ceres. While Ceres is thought to be differentiated, its density is too low to have a substantial iron core [18], and thus Ceres could not have a dynamo either. Smaller asteroids would cool even more quickly than Vesta, and impacts energetic enough to melt their cores would instead break them up.

A transient dynamo driven by impact heating is potentially testable. Crustal rocks that cool in the presence of a magnetic field take on a remanent magnetization. Crustal magnetic fields have been observed on Mars where no global field is present [19]. Thus if a dynamo was operating at the time the rocks within the Australis basin cooled, we would expect to observe crustal magnetic fields over the basin, and not the rest of the planet. The Dawn mission will arrive at Vesta later this year, but sadly carries no magnetometer. However, there may be other observations we can make to infer the presence or absence of magnetized crust.

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