BEATING UP PLUTO: MODELING LARGE IMPACTS WITH STRENGTH. E. J. Davies[1], S. T. Stewart[1]. [1]Department of Earth and Planetary Sciences, U. California, Davis, CA (ejdavies@ucdavis.edu).

Introduction: The recent New Horizons observations have fundamentally changed thinking about Pluto. The geology on Pluto has a rich variety of terrains that differs from other largely icy bodies. Mountains and plains are surprisingly common, and parts of the surface appear young due to the lack of a large number of craters [1]. Atmospheric activity, i.e. condensing and vaporizing hydrocarbons, and glacial flow of N_2, CO, or CH_4 ices at Pluto surface conditions [1] may drive widespread resurfacing. Geological activity could also remove craters through processes such as cryovolcanism and convection of N_2 ices, if Pluto is warm enough to drive it.

Pluto should be a solid, cold body given its size and temperature flux through its surface over 4 billion years. However, a giant impact event, such as the one that created Earth's moon, likely created the Pluto-Charon system [2] [3] [4]. These giant impacts impart massive amounts of energy into bodies that can melt large portions of the planet [5]. However, the impact energy is not deposited homogeneously. Material strength increases the localization of shock energy during giant impact events [7]. Although the size of these impacts is firmly in the gravity-dominated regime for transient crater formation, the final spatial distribution of impact energy is dominated by the residual strength of materials, leading to a localization of impact energy. Therefore, we include a state of the art rheology model in this work [6]. Here, we consider two classes of impacts: giant impacts that could have formed the Pluto system and basin-forming impacts that could have generated long-lived large-scale structures on Pluto, such as Sputnik Planum.

The thermal evolution after an impact event will be sensitive to the temperature distribution in the post-impact state. Here, we show preliminary results of impact calculations including material strength. Strength affects the final distribution of impact energy in the post-impact body as shown in simulations of a collisional origin of the Haumea system [7]. Finally, we present calculations for the cooling rate of the thermal profile of the post impact state.

Numerical Method: We conducted impact simulations using the 3D Eulerian shock physics code CTH [8], including self-gravity [9]. Ice and rock were modeled using multi-phase equation of states for water [10] and forsterite [11]. The pressure, temperature, and strain-rate dependent rheological model includes a brittle regime for the crust and uppermost mantle [12, 13] and a creep regime for the deeper mantle [14]. The rheological model weakens ice at the melting curve of water. The peridotite solidus and olivine liquidus are used to calculate melting of rock [15]. Crater collapse involves a two-phase flow of melt and solid clasts. This complex debris flow is modeled using a simplified approach: when the temperature exceeds the solidus, (i) a pressure-dependent friction law (coefficient of 0.1–0.2 based on melt-lubricated faults [16]) is used at high strain rates ($>10^{-4}$ s^{-1}) and (ii) a Newtonian fluid rheology is used at low strain rates (when the viscosity of the fluid dominates [17]). Model parameters are constrained by laboratory data.

For this initial study, we considered nominal giant impact and basin-forming impact scenarios (Figure 1). In the first case, a Pluto sized object is initialized along with a 300 km radius dunite projectile impacting head on to 45 degrees. The nominal internal structure for Pluto has a rock/icy core to ~850 km radius, with an ice mantle extending to 1200 km. The second kind of simulation involves two half Pluto mass objects with similar proportions of rock-ice, impacting each other at approximately 45 degrees. Temperature profiles are varied because there is a temperature dependence in the rheological model.

Thermal evolution is calculated for the post impact state, taking into account heat generation by radioactive elements with CI chondrite abundances [18]. We use the heat equation to solve for heat diffusion. Heat loss is assumed to be through grey body radiation. We calculated one and two-dimensional solutions. The post-impact state is evolved over billion year time scales to find the rate at which localized heating diffuses to its surroundings and is lost to space.

Sputnik Planum Impact Hypothesis: The lack of impact craters on the informally named Sputnik Planum suggest recent resurfacing within the last 10 million years, whereas the rest of Pluto is ancient [19]. It has been shown that the surface in Sputnik Planum is primarily composed of N_2 ice. Nitrogen ice is extraordinarily weak and can convect with a small heat flux [20]. Therefore, Sputnik Planum is likely the site of a large plain of convecting nitrogen ice.

The localization of the convecting phenomena could be explained by the residual heat from a single basin-scale impact event. Figure 1 shows the results of a simulation of such an impact. Our calculations show that heating by the impact is substantial as well as local. Thus, an impact may provide the modification of Pluto's crust to allow for a contained plain of nitrogen ice. Furthermore, we present thermal evolution calculations that show heating may be long lasting enough to drive convection in nitrogen ices billions of years after the impact.

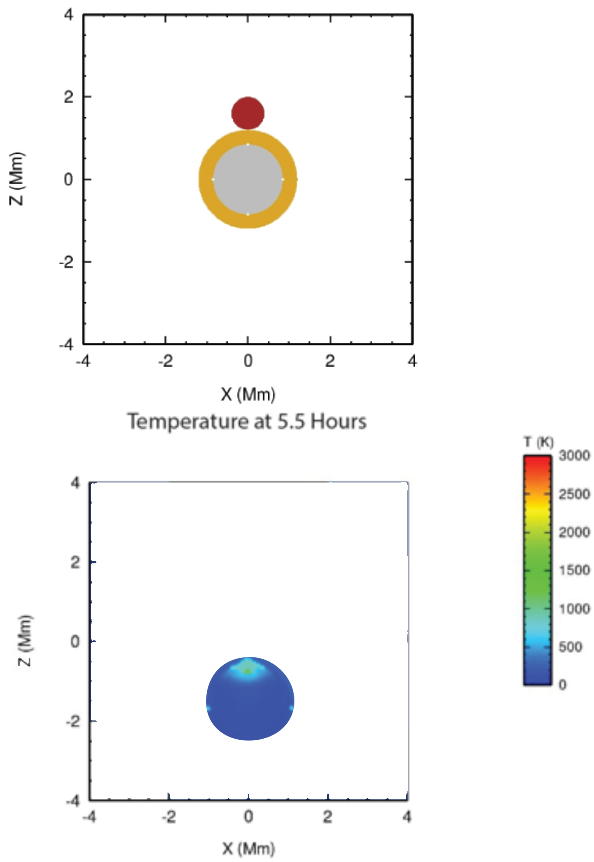

Figure 1: Results of Pluto impacted by a 400 km dunite (brown) projectile at 3 km/s with a strength model. The model Pluto has a rocky/ice core with a radius of 850 km (gray), and an ice shell with a radius of 1200 km (orange). The final thermal profile shows localized heating of Pluto with a peak temperature increase of approximately 1000 K. Disregarding strength in simulations causes more mixing and "sloshing" that leads to more homogenous energy deposition.

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