CHEMICAL PROCESSING OF SOLIDS ENCOUNTERING FORMING GIANT PLANET CORES. M. N. Barnett[1] and F. J. Ciesla[1], [1]The University of Chicago, Department of Geophysical Sciences (meganbarnett@uchicago.edu)

Introduction: A forming Jupiter has been proposed to have played a pivotal role in shaping the properties of the Solar System, sculpting the gas and solids in the solar nebula through its gravitational influence. This includes having served as a barrier to radial drift of solids, possibly maintaining the isotopically distinct reservoirs in meteorites observed today [1]. Such effects would have arisen once Jupiter had reached ~20 M⊕ and continued as it accreted mass throughout the millions of years that the solar nebula remained around the young Sun.

The accretion of mass onto Jupiter and other giant planets at this stage would have released a significant amount of energy that would have gone into warming its surroundings. Such effects have been shown to affect the chemical composition of the surrounding gas, vaporizing ices off of solids and driving chemical reactions that would have not otherwise occurred [2]. Such processing offers a means of identifying signposts of forming planets [2].

The influence of growing planets and planetary cores may still be significant even at lower masses, particularly as models of pebble accretion suggest Jovian cores may grow at rates of up to 10^{-8} $M_{\odot}$/yr [3]. This would warm materials that encounter or are to be accreted by the growing core, altering their chemistry before incorporation into planetary bodies.

Here, we investigate and characterize the thermal and chemical effects that accreting planetary cores have on solid material in the surrounding protoplanetary nebula and the effects this would have on planetary bodies that eventually form.

Methods: We track the dynamical evolution of solids of a variety of sizes in a protoplanetary disk as they move under the combined gravitational effects of a solar mass star and growing planetary core, as well as the effects of gas drag from the surrounding gas [4]. The disk is assumed to have a temperature structure given by [5], and the growing core increases the local temperature based on the assumed accretion rate, size, and local opacity, allowing us to determine the temperature of the solids throughout their trajectories (e.g. Fig. 1).

The resulting thermal profile is then used to model the chemical evolution of the solids. We focus on the retention of key ices such as H_2O, CO, and N_2, using the Polyani-Wagner relation [6,7], and their measured binding energies [5]. As we consider solids of sizes where the stopping time is on the order of their orbital period (Stokes numbers ranging from 0.01 to 10), the velocity of the particles with respect to the gas means any desorbed species will be lost to the gas. This allows us to neglect freeze out, particularly as such a process likely occurs on the smallest solids (fine dust) present as they provide the greatest amount of surface area.

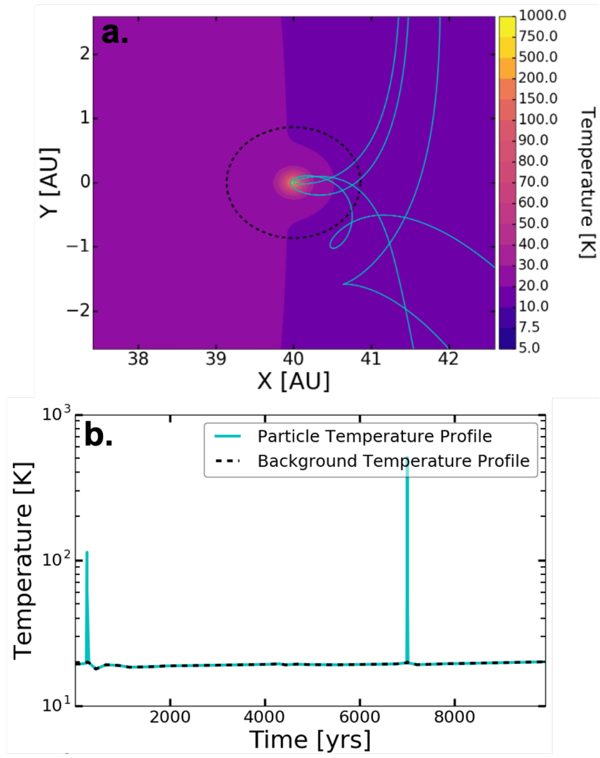

Figure 1: Panel a displays the temperature contours present in the area surrounding a 10 M_{Earth} giant planet core with semi-major axis of 40AU (panel a), featuring an overlain line showing the trajectory of a particle during a fiducial 10,000 year model run for a St=10 particle (cyan solid line) in the core's frame of reference. The dashed line denotes the core's Hill radii. The corresponding temperature evolution experienced by that particle is shown below in panel b. For this model run, the core mass accretion rate is 10^{-9} $M_{\odot}$/yr and the disk is dust rich.

Initial Results: Figure 1 shows an example of the trajectory of a St=10 particle that originates at a distance of 2AU exterior to the planetary core. Over the time period of interest, the particle has two close encounters with the growing core, one ~200 years into the simulation, and another nearly 7000 years in. The thermal consequences of these encounters are shown in the bottom panel.

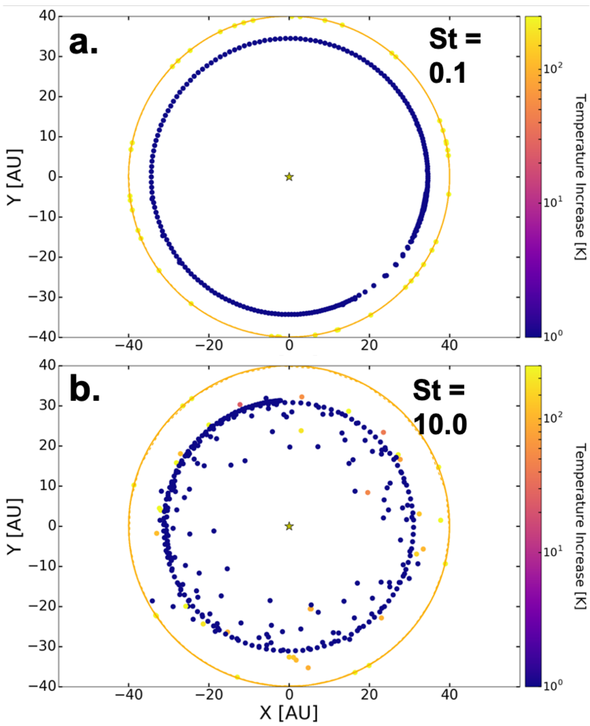

Figure 2: Displayed are the final x and y locations with respect to the central star for 360 particle evolution tracks (circles) for particles of two initial Stokes numbers (labeled). The solid orange line denotes the orbital path of the planetary core. The temperature enhancement each particle felt at its closest core approach relative to the disk background temperature is denoted by color. The core has a mass accretion rate of 10^{-9} $M_{\odot}$/yr and is in a dust-rich disk.

The details of the close encounters that particles experience depends on their starting locations and Stokes numbers. Figure 2 shows the influence of the core on a ring of particles that began with semi-major axes around the Sun that were 2 AU greater than the growing core. Particles were followed for 10,000 years, and the top panel shows the final locations of the St=0.1 particles while the bottom panel shows the St=10 particles. 11.7% of the St=0.1 particles were accreted by the growing core during this time, while 2.5% of the St=10 particles were. The colors indicate the largest temperature excursion experienced by the surviving solids due to their interaction with the planetary core. In contrast to the larger solids, the surviving small particles do not see much of a thermal perturbation (<1 K), though those that are accreted by the planet experience significant warming before reaching the core.

The chemical consequences on solids encountering a planetary core are shown in Figure 3 for the particle model highlighted in Figure 1. The particle encounters the core twice, resulting in two large temperature spikes up to 100 K at 200 years and 450K at 7000 years. The first temperature spike results in full depletion of CO and N_2 on the solid, which have similar binding energies while the solid's H_2O is maintained until the second temperature spike.

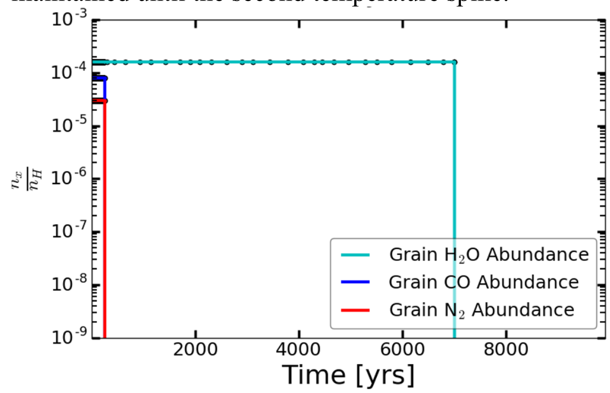

Figure 3: Corresponding chemical evolution for particle model discussed in Figure 1.

Discussion: Thus far, our results focus on the chemical effects of core masses of $10M_{\oplus}$. We are currently exploring the dependence that chemical processing of solids has on core size, accretion rate, and core semi-major axis to understand the effects that the planet has on solids throughout its growth.

Nonetheless, our initial results demonstrate that thermal and chemical processing of solids as they move near growing giant planet cores can be significant. These solids, after such processing, continue to drift through the disk and are available to be incorporated into growing planetesimals or satellitesimals. As such, larger bodies born from these processed solids could be depleted in various volatiles. We continue to explore the consequences of these changes on the properties of forming planetary bodies.

References: [1] Kruijer, T. S. et al. (2017) PNAS 114, 6712–6716. [2] Cleeves, L. I. et al. (2015) ApJ 807, 2. [3] Lambrechts, M. & Johansen, A. (2012) *A&A* **544**, A32. [4] Tanigawa, T. et al. (2014) ApJ 784, 109. [5] Oberg, K. I. & Wordsworth, R. (2019) AJ 158, 194. [6] Hollenbach, D. et al. (2008) ApJ 690, 1497–1521. [7] Piso, A.-M. A. et al. (2015) ApJ 815, 109.