EXPERIMENTAL AND THEORETICAL PROGRESS ON THE FLYBY MODEL FOR CHONDRULE AND CHONDRITE FORMATION. J. P. Greenwood[1] and W. Herbst[2], [1]Dept. of Earth and Environmental Sciences, Wesleyan University (Middletown, CT USA, jgreenwood@wesleyan.edu), [2]Dept. of Astronomy, Wesleyan University (Middletown, CT USA).

Introduction: While there are an astonishing abundance of models that posit a mechanism for chondrule formation, there are almost no models or ideas for the formation of the chondritic meteorites themselves. We have previously proposed a model for the formation of chondrules by radiative heating as dust grains make close flybys of molten planetesimals [1]. We have recently extended this model to produce both chondrules and chondrites during the same event [2].

Flyby Model for Chondrule and Chondrite Formation: Chondrules and chondrites are formed during a brief heating event caused by the close encounter of small (m to km-scale) primitive planetesimals (SPP) with an incandescent lava on the surface of large (100 km-scale) differentiated planetesimals (LDP) (Figure 1). A radiative heating model developed for the SPPs predicts possible thermal histories that are highly constrained in temperature-time space. Our model predicts symmetrical heating and cooling curves (called thermal trajectories) that are similar in overall time and temperature space as constraints from chondrule synthesis experiments [e.g. 3].

Small Primitive Planetesimal (SPP): The SPP is highly porous and low-density, and contains all the materials found in chondrites, including presolar grains and organics. Heating of the SPP will lead to regions that will not reach chondrule liquidus temperatures. Thus, vaporization of low temperature materials in the hot zones (where chondrules are formed), as well as preservation of low-temperature materials in the cooler regions of the SPP are predicted. The heated SPP would naturally provide an environment enriched in Na, Si, and other volatile elements. The heating of the SPP will cause compaction and densification, via a process called Hot Isostatic Pressing (HIP), which is akin to the industrial process of sintering. The geometry of our model for the heating of the SPP is shown in Fig. 2.

Experiments: We are currently undertaking chondrule synthesis experiments using the predicted thermal trajectories of the flyby model [2]. We are working with a wide range of precursor materials and hope to present results at the meeting on several of these precursor assemblages. We are also working on reproducing chondrule mineral and glass chemistry, especially relict Al and Ti zonation of olivine [4]. Here we present results of the synthesis of Type I porphyritic olivine chondrules.

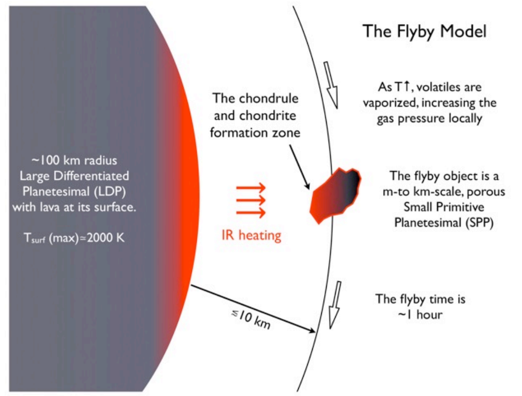

Figure 1. Schematic of the Flyby Model.

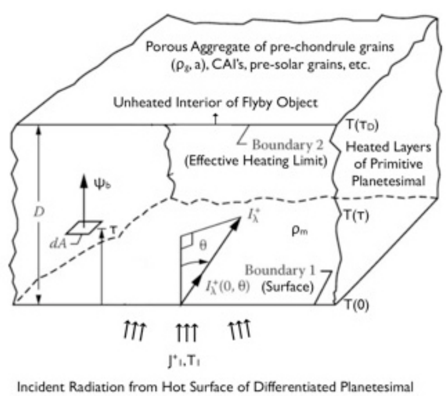

Figure 2. Geometry of our model for the heating of the SPP during a close flyby of a hot source. The layer contains all the material necessary for a chondrite and is characterized by a depth D, that achieves thermal equilibrium, an opacity, κ, a mean density ρ_m, and a Bond albedo, A. The opacity is primarily from grains of radius a, and grain density ρ_g. Infrared radiation is incident on the surface of the SPP from below and penetrates upward to an optical depth of τ_D. See [2] for more details.

Experimental Details: Natural peridotite xenolith from Globe, AZ was picked, cleaned and sieved to <20 μm and mixed with plagioclase feldspars (Miyake anorthite and Salva Tierra oligoclase) of similar grain size, along with graphite with or without TiO_2 in either

Pt rings or sintered onto Pt wire. As the natural peridotite has more oxidized iron than typically expected for Type I chondrules [3], a subset of experiments were pre-conditioned in Pt rings at IW-1.

Experiments were run in a Deltech furnace under controlled atmospheres. Temperatures were monitored with Type B thermocouple. A 16-step programmable Eurotherm 2404 was programmed with linear segments to mimic the thermal trajectories of the flyby model. Oxygen fugacity was controlled to IW-1 using mixtures of CO and CO_2 gases and mass flow controllers. Resulting experimental charges were analyzed using the Wesleyan University Hitachi SU5000 FEG-SEM using EDAX Apollo 10/X/Octane Pro SiDD.

Experimental Results: Using the new thermal trajectories of [2] leads to overall shorter thermal histories than previously employed. Shown in Fig. 3 are thermal trajectories for Fig. 4 and Fig. 5 of [2] in black, and an actual experiment in red (Fig.5_2km1b). The resulting texture of porphyritic olivine and glass is shown in Fig. 4 for this experiment. Resulting olivine is $Fo_{98\text{-}100}$. An interesting result of this much shorter thermal history is that Na was not lost from the experimental glass. The composition of the experimental glass is compared to the average Type I chondrule glass of Semarkona [5] in Fig. 5. We also made the precursor of this experiment with a Ti-free inner half and a 1 wt.% TiO_2 outer half. Interestingly, TiO_2 was homogenized during the experiment, while Na_2O was not lost (Fig. 5).

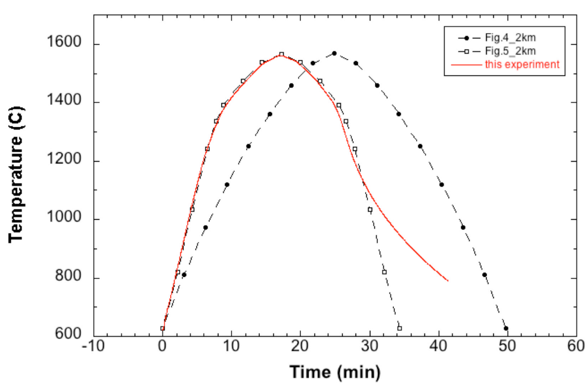

Figure 3. Thermal trajectories for two sets of experiments. Red line shows the actual recorded temperature profile. The Fig.4_2km curve is for a 2 km closest approach to a fully molten planetesimal of 100 km radius. The Fig.5_2km curve is for the same 2 km approach to a 100 km planetesimal, but with only 25% lava coverage.

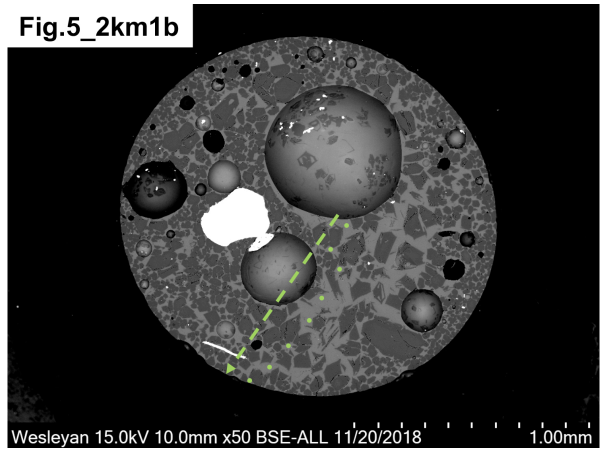

Figure 4. Experiment whose thermal trajectory is shown in red in Fig. 3. All grains are Fo98-100. White is Pt wire, and green spots show the spot# in Fig. 5.

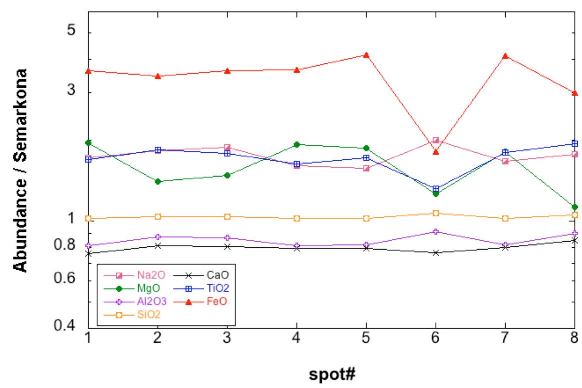

Fig. 5. Composition of glass in Fig. 4 normalized to average Type I chondrule glass in Semarkona [5]. The eight spots are from core to rim and shown in Fig. 4.

Summary and Implications: The flyby model for chondrule formation appears to be able to fit the constraints imposed on chondrule and chondrite formation by the objects themselves. If the model is coupled to that of [6], then one can plausibly explain parent-body metamorphism as well.

References:

[1] Herbst W. and Greenwood J. P. (2016) *Icarus, 267,* 364-367. [2] Herbst W. and Greenwood J. P. (2019) *Icarus in review.* [3] Connolly Jr. H. C. and Jones R. H. (2016) *JGR Planets 121,* 1885–1899. [4] Marrocchi Y. et al. (2018) *EPSL 496,* 132-141. [5] Alexander C.M.O'D. et al. (2008) *Science 320,* 1617. [6] Elkins-Tanton L. T. et al. (2011) *EPSL 305,* 1-10.