EXPERIMENTAL CONSTRAINTS ON INDUCTION HEATING IN THE EARLY SOLAR SYSTEM. C. A. Marsh[1], D. S. Lauretta[1], J. Giacalone[1], [1]Univeristy of Arizona, Lunar and Planetary Laboratory, Tucson, AZ 85721, USA (celinda@lpl.arizona.edu)

Introduction: Induction heating is the release of thermal energy within a body due to the resistance of that material to a current passing through it. This is also called Joule heating or Ohmic dissipation. Induction heating has been proposed as a process that could have caused metamorphism and melting in planetesimals in the early solar system [1]. While not widely studied, this hypothesis is still discussed in the meteorite and asteroid communities as a source of heat in asteroids [2, 3].

In order to have induction heating a magnetic field must be present of sufficient strength to induce a current in the materials present. When Sonnet and co-workers proposed induction heating in the early solar system they assumed a magnetic field originatign in the protostar which is carried outward by the expanding solar wind. Recent observations and models have reduced the estimated intensity of the T-Tauri stage solar wind, especially in the mid-plane [4, 5]. Some authors have used these observations to argue against induction heating of planetesimals [6].

However, an additional magnetic field source active in protoplanetary nebulas around T-Tauri stars has been recognized in the last 15 years [7]. Magnetorotational instability (MRI) arises due to the magnetic field lines between two packets of ionized gas being stretched as the two packets orbit a protosun. The stretching of magnetic field lines has two effects: it strengthens the magnetic field between the two packets of gas, and it transports angular momentum between the ionized gas packets as well as neutral particles the ionized gas packets are coupled to. MRI may be necessary to explain the transport of angular momentum required for accretion to take place in protoplanetary disks [8]. The presence of MRI in protoplanetary nebula regions with sufficient ionization is widely accepted [e.g., 9]. In modeling the MRI, it has been found that the magnetic field strength will increase until the energy gain of the system is balanced with an increase in thermal energy, mostly due to Joule heating [10]. However, this model predicts Joule heating in the gas of the protoplanetary disk, not solid particles. In fact, the effect of dust and solids on MRI is an area in need of further refinement in most models of MRI and/or ionization of the protoplanetary disk [11].

Meteoritic Constraints: The available meteoritic and asteroidal evidence indicates the presence of an intense, selective, and short-lived heat source in the very early solar system. The chronology of meteoritic heating events, indicators of parent-body size derived from cooling histories, and the spatial distribution of asteroid types provide constraints for the analysis of proposed heating mechanisms.

Experimental Methods: We seek an upper limit to the intensity of the magnetic field experienced by chondritic materials in the early solar system by measuring the field strength required to heat chondritic materials in the lab.

Our procedure is close to that of previous work [12], with the exception that experiments are performed using an Ameritherm HotShot radio frequency (RF) induction heating station. This device is designed to heat small objects using frequencies from 150 to 400 kHz with up to 2 kW of power. The RF radiation is generated using a water-cooled copper induction heating coil. The geometry of the coil can be varied to accommodate a variety of sample sizes. Heating is achieved through Joule heating resulting from Eddy currents in electrically conductive material. Temperatures up to 2000 ^{o}C can be achieved within seconds. The length of the heating cycle can be varied from 10 milliseconds up to 3 hours. Temperature is monitored throughout the experiment by using an Omega OS37-10-K pyrometer and DPi32 temperature logging system.

The materials used in our experiments are pellets of cutting dust from a pallasite, controlled mixtures of olivine and metal, and ultimately cubes obtained from the centers of ordinary chondrites. Grain sizes and composition are measured in control samples in all cases through optical microscope and electron microprobe analysis.

Once a sample has undergone Joule heating and returned to room temperature, it is removed from the furnace and weighed to determine the mass difference. The surface of the sample is characterized by optical microscopy, scanning-electron microscopy, and energy dispersive spectroscopy. The sample is then be mounted in epoxy and polished for electron microprobe analysis (EMPA) and laser-ablation ICP-MS. EMPA provides information on the main mineral phases and the distribution of major elements between the metal and silicates, and the compositional variation with distance from the interface. ICP-MS analyses provides information on the partitioning of trace elements between phases. We apply our newly-developed quantitative X-ray mapping technique to determine the amount of elemental mobilization that occurs during each experiment [13].

Discussion: There are several additional factors that need to be considered before an upper limit on field strength in the solar nebula can be calculated. The frequencies at which our induction furnace operates are higher than those expected in the early solar system. In addition, chondritic parent bodies are modeled as being 10s of km in diameter. Therefore, current density with depth will be quantitatively modeled before the difference between magnetic field strength at the surface and the location of various thermal metamorphic zones in the parent body can be assessed.

A quantitative estimate of the magnetic field strength required to cause thermal metamorphism in the ordinary chondrites will either place an upper limit on the strength of the magnetic field(s) present in the early solar system or disprove the induction heating hypothesis.

References: [1] Sonett, C.P., Colburn, D.S., *et al.* (1968) *Nature* 219: 924-&. [2] Ghosh, A., Weidenschilling, S.J., *et al.* Forthcoming. In *Meteorites and the Early Solar System II.* [3] McSween, H.Y., Ghosh, A., *et al.* (2002): In *Asteroids III*. [4] Decampli, W.M. (1981) Astrophys J 244: 124-146. [5] Edwards, S., Cabrit, S., *et al.* (1987) *Astrophys J* 321: 473-495. [6] Wood, J.A., Pellas, P. (1991): In *The Sun in Time*. [7] Balbus, S.A., Hawley, J.F. (1991) *Astrophys J* 376: 214-233. [8] Balbus, S.A., Hawley, J.F. (2000) *Space Sci Rev* 92: 39-54. [9] Boss, A.P., Goswami, J.N. Forthcoming. In *Meteorites and the Early Solar System II.* [10] Sano, T., Inutsuka, S.-i. (2001) *Astrophys J* 561: L179-L182. [11] Fleming, T., Stone, J.M. (2003) *Astrophys J* 585: 908-920. [12] Lauretta, D.S., Lodders, K., *et al.* (1997) *EPSL* 151: 289-301. [13] Marsh, C.A., Lauretta, D.S., *et al.* Forthcoming. *Meteoritics & Planet. Sci.* 40: Supplement.