HEAT CAPACITY MEASUREMENTS OF HED METEORITES FROM THE VATICAN COLLECTION.

R. J. Macke[1], G. J. Consolmagno[1], and D. T. Britt[2] [1]Vatican Observatory, V-00120 Vatican City State macke@alum.mit.edu, [2]Dept. of Physics, University of Central Florida, Orlando FL.

Introduction: In addition to physical properties such as density and porosity, thermal properties such as heat capacity and thermal conductivity are keys to understanding asteroid formation and evolution, and their influence on dynamic behaviors such as those caused by YORP and Yarkovsky effects. Direct measurements of these properties in meteorites is preferable to inferring them from assumed compositions, but to date very few meteorite physical properties have been measured.

The achondrites known as howardites, eucrites and diogenites (HED) are believed to have originated from the asteroid 4 Vesta [1], which was recently the subject of a flyby by the Dawn spacecraft [cf. 2]. Improved thermal properties data are key to interpreting some of the dynamical data from that mission. With our recent development of the technique of liquid nitrogen immersion for measuring heat capacities, we have conducted and report here preliminary results from heat capacity measurements on 12 samples of HED meteorites in the Vatican collection. These include two howardites, seven eucrites, and three diogenites.

Measurement: Our technique, including systematic effects, is described in [3]. A sample at room temperature is dropped into a dewar that sits upon a scale. As the sample cools to the temperature of liquid nitrogen (77.5 K), it causes a quantity of liquid nitrogen to boil away. By recording the mass of the apparatus at regular intervals via computer, the quantity of LN_2 lost due to the temperature change can be determined, from which an estimate of the heat capacity of the sample at an average temperature of about 175 K can be calculated. Because of the sensitivity of this technique to uncontrollable factors, a minimum of five independent measurements are made per sample.

Our samples ranged in mass from 5.2 g to 70.9 g. Ideally, all samples should be greater than 15 g in order to ensure homogeneity and to reduce the overall effect of environmental factors such as the absorption or adsorption of water. At present, we lacked access to samples of greater mass particularly among the howardites. Among the twelve samples measured were three diogenites (Bilanga, Roda, and Shalka), seven stones of four eucrites (Jonzac, Juvinas [3 stones], and Stannern [2 stones] and Dar al Gani 411), and two howardites (Le Teilleul and Pavlovka). Of the eucrites, all but DaG 411 are monomict.

The heat capacity data were added to our database of other physical properties of density, porosity, and magnetic susceptibility. For those samples that did not already have a complete suite of physical property data, the missing measurements were conducted. Our methods, which are non destructive and non contaminating, are described in detail in [4],[5]. Grain density is measured via ideal gas pycnometry using nitrogen (or helium for samples measured previously). Bulk density is measured using glass bead immersion. Porosity is calculated from these two densities. Magnetic susceptibility is measured using an SM-30 device.

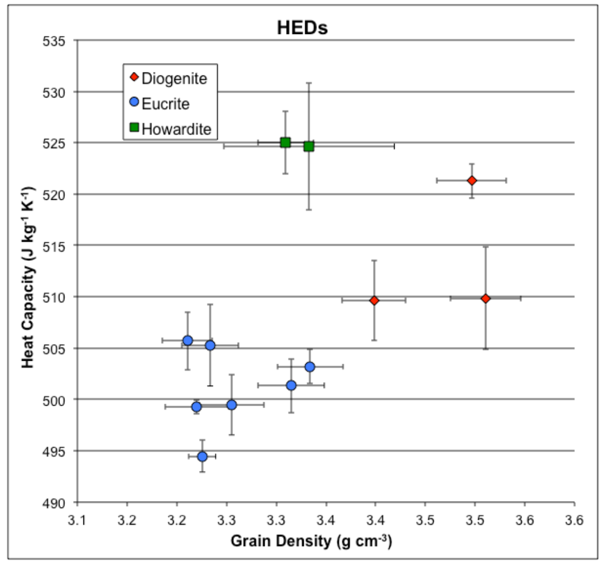

Figure 1: Heat capacity vs. grain density for HEDs in this study. Note that the two howardite samples are relatively small and may not represent howarditic material in general.

Results: (Table 1, Fig. 1) Heat capacities ranged from 495 to 523 J kg^{-1} K^{-1}. Eucrites were in the lower part of this range, from 495 to 505 J kg^{-1} K^{-1}. Diogenites ranged from 510 to 521 J kg^{-1} K^{-1}. Howardites, being a mix of diogenite and eucrite, should have heat capacities ranging between the two, but instead had the highest heat capacities of the set, around 525 J kg^{-1} K^{-1}. Both of the howardites in this study were very small: Le Teilleul is 5.24 g and Pavlovka 8.14 g, and small sizes may have a significant effect on results (see discussion below). Measured low-temperature heat capacities of pyroxenes range from 500-520 J kg^{-1} K^{-1}[6], so to first order our results are consistent with their mineral analogues.

Discussion: These represent preliminary results for HEDs, and should not as yet be considered wholly representative of the class. Nevertheless, there are

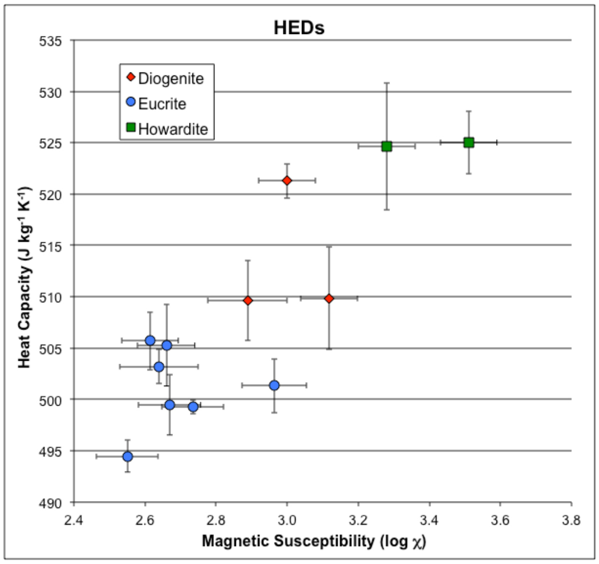

Figure 2: Heat capacity vs. magnetic susceptibility for HEDs in this study.

some intriguing trends worth further exploration. For instance, heat capacities correlate positively with magnetic susceptibility (Fig. 2). This is unexpected, since higher magnetic susceptibility is usually the result of increased iron content, which should decrease rather than increase heat capacity. No clear correlation exists between heat capacity and porosity or grain density.

These trends are relatively small when compared with the whole range of meteorite types. When compared with other meteorites for which we have measured heat capacities (Fig. 3), HEDs compare well with other achondrites, and on average have slightly higher heat capacities than ordinary chondrites and much higher heat capacities than unweathered irons.

Small masses: The presence of some very small stones in this study may have an effect on the overall results. In addition to greater random error among small samples, and greater sensitivity to the particular method of calculating the quantity of LN_2 boiled away, we have observed a consistent mass-related trend in heat capacities among HEDs, with smaller samples (below 15 g) having higher heat capacities than larger ones. Because of the peculiarities of the collection, howardites were among the smallest samples, the diogenites in the mid-size range, and the eucrites were the largest, making it impossible to distinguish external effects from effects due to genuine differences between the meteorites. We note, however, that there is no obvious mineralogical factor that would account for this.

If the effect is external, the most likely culprit is water adsorbed from atmospheric humidity. We calculate that the addition of just 0.03 – 0.04 g of water per sample would account for this effect. Further studies are planned to explore this possibility.

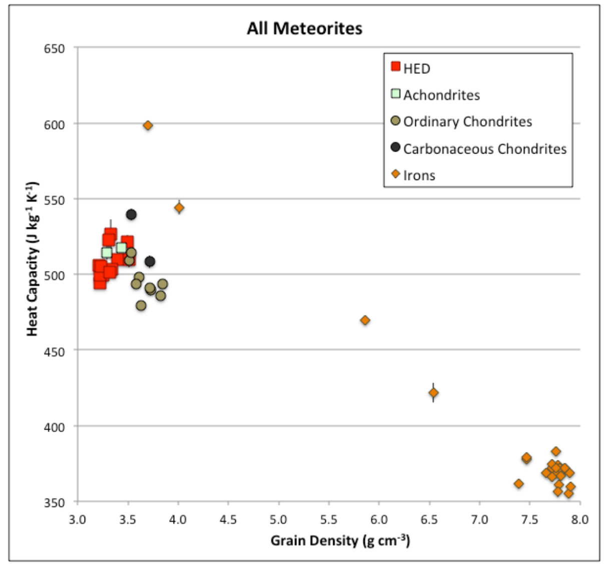

Figure 3: Heat capacity vs. grain density for all meteorites we have measured to date. HEDs are in red squares. Iron meteorites include a mix of fresh and weathered samples.

References: [1] Consolmagno G. J. and Drake M. J. (1977) *Geochim. Cosmochim. Acta* 41, 1271-1282. [2] Russell C. T. and the Dawn Team (2012) *Science* 336, 684-686. [3] Consolmagno et al. (2013) *Planet. Space Sci.* 87, 146-156. [4] Macke (2010) Univ. Central Fla. PhD Thesis. [5] Consolmagno G. J. et al. (2008) *Chemie der Erde – Geochem.* 68, 1-29. [6] Krupka K. M et al. (1985) *Amer. Mineralogist* 70, 249-260.

Table 1: Heat capacities of meteorites in this study. These values are preliminary and may be adjusted later for factors such as sample mass.

Meteorite Name	**Mass (g)**	**Type**	**Heat Capacity ($J\ kg^{-1}\ K^{-1}$)**		
Bilanga	14.58	Dio	**509.7**	±	**3.9**
Roda	7.42	Dio	**521.3**	±	**1.7**
Shalka	18.42	Dio	**509.8**	±	**5.0**
Jonzac	31.86	Euc	**499.5**	±	**2.9**
Juvinas	31.36	Euc	**494.5**	±	**1.5**
Juvinas	70.94	Euc	**499.3**	±	**0.7**
Juvinas	16.49	Euc	**505.7**	±	**2.8**
Stannern	18.54	Euc	**503.2**	±	**1.7**
Stannern	14.98	Euc	**505.3**	±	**4.0**
Dar al Gani 411	19.45	Euc	**501.3**	±	**2.6**
Le Teilleul	5.24	How	**524.6**	±	**6.2**
Pavlovka	8.14	How	**525.0**	±	**3.1**