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Simulating the Atmospheric Entry of Micrometeorites using a Two Stage Light Gas Gun.

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Introduction: It is estimated that 20-30,000 tonnes of extra-terrestrial dust arrives at the Earth per annum [1], with approximately 90% of these particles failing to reach the Earth's surface due to atmospheric entry effects [2]. These dusty particles are largely thought to originate from asteroids and comets, with analysis of micrometeorites - those particles that survive atmospheric entry - suggesting that they sample a larger number of parent bodies than currently represented in meteorite collections [3,4]. Micrometeorites (MMs) can therefore potentially provide a more complete picture of the contents, formation and evolution of our solar system than meteorites alone.

Due to the extreme conditions MMs experience during their entry through the Earth's atmosphere, many have experienced chemical and morphological alteration. Those that have experienced complete melting are referred to as cosmic spherules and are amongst the most abundant source of extra-terrestrial material on the Earth [5]. In order to interpret details of their original compositions and therefore gain insights into the composition and history of their parent bodies. A greater understanding of the processes that they have undergone during atmospheric entry is needed [6]. As vaporisation also occurs during entry, understanding entry processes will also provide insight into the contribution these particles make to the Earth's atmosphere and the role they have played in its evolution [7].

Previously, experiments aimed at investigating atmospheric entry have relied on the use of stationary pulse heating techniques, exposing a number of MM analogues to similar heating conditions as those experienced by MMs [e.g. 8,9]. During these experiments the analogues are heated uniformly, however, due to the non-uniform shape of the incoming progenitor particles they are likely to tumble during entry, resulting in non-symmetrical heating patterns and the possible differentiation of the molten materials [10]. These effects would not be replicated during stationary heating, therefore features such as flight morphology and loss of non-volatiles are not reproduced [9]. Attempts have also been made to investigate entry effects using computational modelling. These studies have focused on the loss of ablated material, providing results that suggest material of a cometary origin is able to survive entry through the atmosphere [11]. More recently, Reddy shock tubes have been used to examine alteration effects associated with instantaneous shock events and may also provide another valuable method for investigating the atmospheric entry processes [12].

Here we report on the results of our attempts to replicate the effect of atmospheric entry on MMs using the two stage light gas gun (LGG) at the University of Kent.

Method: The LGG is capable of accelerating projectiles up to 3 mm in diameter at velocities up to 7.5 kms^{-1} [13]. During shots, however, the LGG requires that the target chamber be pumped down to pressures below 50 mbar prior to being fired. In order to fire through an atmosphere, and thus simulate atmospheric entry, we have therefore designed a 1 m long environment tube that can fit within the LGG target chamber (see Fig. 1). The environment tube is able to contain a range of non-corrosive gases at a range of pressures up to 5 bar. The front of the environment tube is covered with a Mylar film, designed to be pierced by a 'buckshot' of glass spheres (~120 µm) fired immediately preceding the projectile (see Fig. 2) and then ruptured by the pressure of the contained gas prior to the passage of the primary projectile.

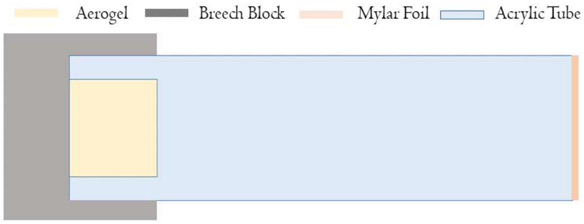

Fig. 1: The environment tube, showing the position of the aerogel and Mylar film.

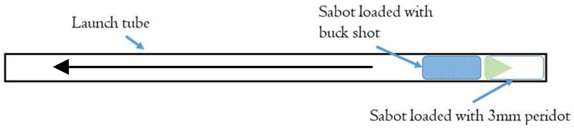

Fig. 2: The loading of the olivine and buckshot in the launch tube of the LGG prior to firing

The primary projectiles used for these shots were olivine (Fo90) gemstones cut in the brilliant fashion and with a girdle width of 3 mm. Cut gemstones were chosen so that analysis of any melting and ablation of the projectile could be easily measured.

Prior to each shot the olivine was characterised optically and via scanning electron microscopy with energy dispersive X-ray microanalysis (SEM EDX,) and with Raman spectroscopy.

Following its passage through the environment tube, the olivine was decelerated and captured in a block of aerogel. Aerogel was chosen as its ability to capture particles travelling at hypervelocity have been well studied, having been used to capture dust particles by a number of missions (e.g. the Orbital Debris Collector on MIR [14], the Stardust mission to comet 81P/Wild 2 [15] and the Tanpopo experiment on the International Space Station [16]). In order to identify features resulting from passage through the atmosphere vs. features resulting from capture in the aerogel, shots were performed in pairs, with and without air contained in the environment tube such that comparisons could be made.

After firing, each olivine was removed from the aerogel, imaged both optically and via SEM and embedded in resin. The embedded samples were then cut perpendicularly through the table such that its cross section outcropped at the surface ready for analysis.

Results: Olivines were shot at a range of velocities into the environment tube containing air. Analysis of the olivines following their removal from the aerogel block showed that for velocities of 2.5 km s^{-1} and lower the gemstone remained intact. Those particles accelerated to velocities exceeding this were found to have disintegrated en-route, likely during launch.

SEM analyses revealed welding of molten aerogel to the surface of our projectiles at speeds exceeding 1 kms^{-1}. We have also observed an enrichment of iron along the front face of the projectile. We aim to proform further analysis of these samples using transmission electron microscopy to determine whether the iron enrichment observed is related to the molten aerogel and identify any finer scale changes.

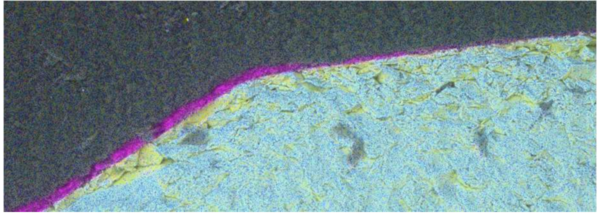

Figure 3: SEM EDX chemical map showing silicon rich aerogel (pink) welded to the surface of the magnesium-iron rich olivine (blue) with iron rich areas (yellow) close to the front face.

Calculations determined that the olivines must be travelling at velocities greater than ~2 km s^{-1} in order to experience melting (being heated to temperatures greater than approximately 2200 K) prior to reaching the end of the atmosphere contained in the environment tube (see Fig. 4). It is therefore likely that our projectiles experienced melting prior to entering the aerogel. In order to observe more significant melting of the olivines in our experiments with the LGG environment tube we therefore propose to increase the pressure of the contained gas instead in future experiments.

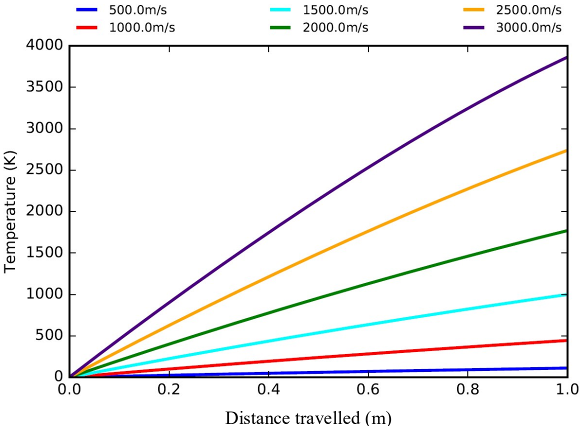

Fig. 4: The calculated surface temperature change in the projectile as it passes through the air at standard atmospheric conditions contained in the environment tube at a range of velocities.

Summary: Preliminary results show the environment chamber permits the simulation of atmospheric entry at a range of entry velocities. Further work is ongoing to analyse the effect of the atmospheric passage on the olivines, with future shots planned using more accurate MM analogues and a range of gas pressures to attain higher temperatures.

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Reference:[1] Taylor, S. et al, (2000), *MAPS , 35,* 651:666 [2] Taylor, S., (1998), *Nature, 392,* 899:903 [3]Noguchi, T. et al, (2015), *Earth. Planet. Sci. Letters, 410,* 1:11 [4] Duprat, J. et al , (2010), *Science, 328,* 742:745[5] Zolensky, M. et al, (1998), *Flux of Extraterrestrial Matter,* 896:888 [6] Genge, M.J. et al, *MAPS, 43,* 497:515[7] Janches, D. et al (2009), *Geophys. Res. Lett.*, *36,* L0601 [8]Greshake, A. et al, (1998), *MAPS, 33,* 267:290[9] Topanni, A. et al, (2001), *MAPS, 36*, 1377:1396 [10] Suttle, M.P. et al, (2017), *Geochim. Cosmochim. Acta*, *206,* 112:136 [11] Bones, D.I. et al, (2016), *Rev. Sci. Instrum., 87,* 094504 [12] Reddy, K.P.J. and Sharath, N., (2013), *Cur. Sci., 87,* 172:176 [13] Burchel, M.J. et al, (1999), *Meas. Sci. Technol., 10,* 41:50 [14] Horz, F., (1999), *NASA* [15] Burchell, M.J. (2008), *MAPS, 43,* 23:40 [16] Yano, H. et al, (2014), *LPSC XXXXV,* Abstract#2934