HYDROCODE SIMULATIONS OF AGGREGATE DUST PARTICLE IMPACTS ONTO STARDUST Al FOILS. M. C. Price[1], A. T. Kearsley[2] and M. J. Burchell[1]. [1] Centre for Astrophysics and Planetary Science, University of Kent, Canterbury, Kent, CT2 7NH, UK (E-mail: mcp2@star.kent.ac.uk), [2] Impacts and Astromaterials Research Centre (IARC), Dept. of Mineralogy, Natural History Museum, London, SW7 5BD, UK.

Introduction: We have used the Ansys Inc. AUTODYN® software [1] to hydrodynamically model small particle impacts into aluminium (Al) foil, under the conditions of the Stardust encounter with comet 81P/Wild 2 [2] (i.e., normal incidence, 6 km s^{-1}). We compare results of impact models, based on carefully defined particle structures, with three-dimensional (3-D) crater shapes reported from Stardust [3,4]. This allows us to assess the extent to which particle construction is reflected in the resulting impact feature, and hence how we might infer impactor structure from crater shape. Our aim is to improve interpretation of Wild 2 dust characteristics, especially sub-grain dimensions, internal porosity and overall grain density. Here we present a simulation of a complex impact seen on Stardust foil C029W,1 [4], and show that a similar shape is consistent with the structure of a reasonably simple aggregate impactor model.

Quantitative 3-D measurement of crater shape: Using MeX software, we produced detailed digital elevation models (DEMs) from stereo-pair scanning electron microscope (SEM) images, and quantified the depth and lateral dimensions [5]. Crater depth is influenced by a number of impactor characteristics, amongst which density is important [5]. DEMs for complex Stardust craters such as Fig. 1, reveal multiple depressions which have been interpreted as implying discrete concentrations of mass within a larger porous particle body [4], yielding very complex crater excavation. But just how realistic is the simplistic internal structural model (Fig. 2) proposed by [4] for this impactor?

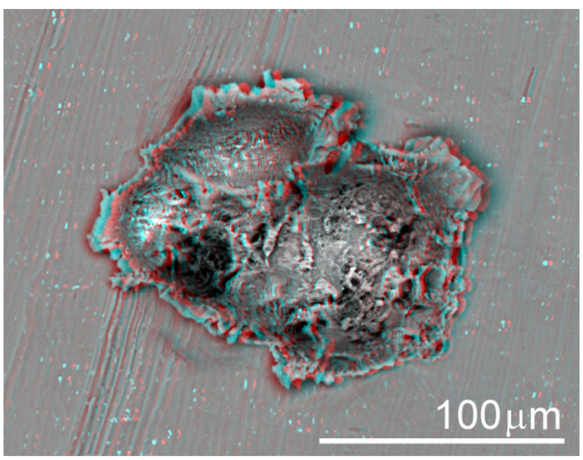

Figure. 1: Stereo anaglyph of backscattered electron images from a complex crater found on foil C029W,1.

Aggregate modelling:

*Proposed impactor***:** The structure of the modelled impacting grain was suggested [4] in order to calculate probable masses of individual sub-grain components, and hence the overall bulk density and porosity. It was based upon assumptions that locations of depth maxima in the DEM reflect points of sub-grain mass concentrations, and that projected diameters of partial sub-circular rim outlines (Fig 2.) could be used to derive sub-grain dimensions, by comparison to the calibrated size relationship for simple craters at 6.1 km s^{-1} [6]. Subsequent measurement of the total sub-surface volume (from a DEM of the complex feature), when compared to a calibration of displaced target volume as a function of spherical glass impactor mass, gives an overall particle mass which closely matches the mass inferred from the simple structure and suggests that use of soda-lime glass properties in a numerical simulation should give reasonable approximation to the real particle. In both the original description and in this simulation, a simplistic assumption is made that all components of the impactor are co-planar (i.e. in 2-D). This is to simplify the initial model and subsequent analysis of results. We are now beginning to model complex aggregates with a third dimension, and intend to substitute different material properties for the sub-grain components according to their analysed residue compositions (e.g. olivine, pyrrhotite etc.).

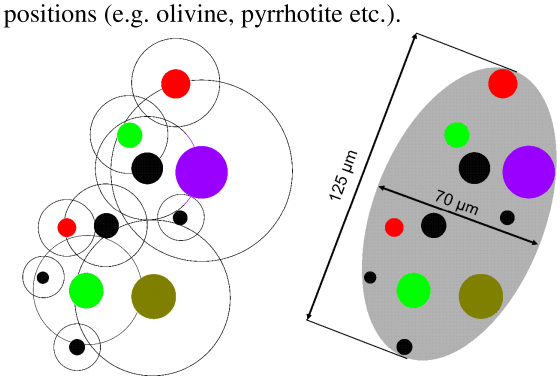

Figure 2: Impactor (modified from [4]) modelled for the structure shown in Fig. 1 (rotated 90^{O} anticlockwise). Likely compositional precursors, based on SEM energy dispersive X-ray (EDX) analyses: red/orange is Fe sulfide: green olivine and pyroxene; purple Ca-rich aluminosilicate: brown mixed sulfide-silicate, black is unresolved.

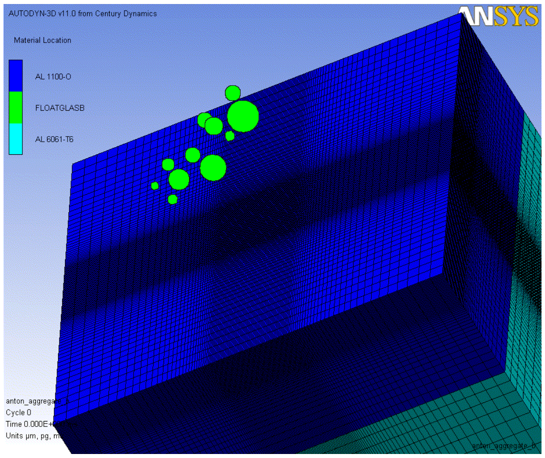

Figure 3: Autodyn-3D model constructed to simulate the impactor, the Al 1100 foil and Al 6061 frame of the spacecraft collector tray.

Autodyn model: AUTODYN-3D (V11.0h) was used and the equations of state (EoS) for both Al alloys and floatglass were taken from the standard AUTODYN library. The aggregate impactor is comprised of 11,472 SPH particles, the Al foil and underlying spacecraft superstructure are a graded lagrangian grid of 121(x) × 121(y) × 61(z) cells (Fig. 3). Transmission planes were placed on the five non-impact planes in order to simulate a semi-infinite target.

Results: Fig. 4 shows the final simulated crater (1 × 10^{-4} ms after impact). Superimposed (as yellow circles) are the positions of the original subgrains. As can be seen, the simulated structure has a very similar morphology to the real structure and shows distinct crater regions separated by well defined septa (although centres of "pits" are offset from the discrete components in the original impactor). The overall X and Y dimensions are comparable to the real structure and it has similar depth profiles as the DEM.

Discussion: In 3-D, the simulation recreates the uplifted margins between bowl-shaped depressions, and the mutual interference that results in truncation of hemispherical shape and circular outline. However, we are well aware of omissions from our impactor structure model, such as the different behaviour of diverse grain compositions, sub-grains of differing shape, whether sub-grains are really denser fine-grained aggregates or single crystal larger particles, the mechanism of grain interlocking or cementation (the grey material in Fig. 2) and its effect on inhibition of internal uplift. Some of these variables will be addressed in future modeling, for example adding particles in the 'missing' third dimension, the use of different material EoS for individual grains, and changing the internal grain size of sub-grains within aggregates. 'Unknowns' that probably cannot be constrained include the nature

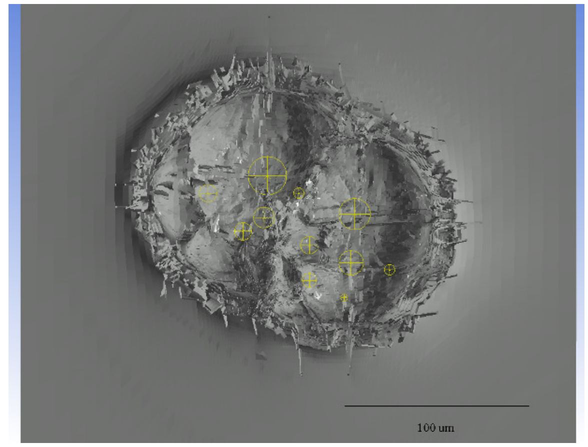

Figure 4: The simulated impact feature morphology, at the end of crater excavation.

of the grain interlock mechanism or cement; although a carbon-bearing residue along the crater edge was reported [4] and shown to be organic (bonded to H), [7], suggesting that 'glue' may be present, as was used in experimental aggregates [8].

Conclusions: Results show that AUTODYN simulations, even with simplistic impactor models, can potentially recreate structures very similar to those found on Stardust foils. The model described herein is based upon a broad, complex, impact feature that suggests spatially dispersed mass concentrations in the impactor. Recent laboratory experiments [8] suggest that tighter concentration of small subgrains into larger particles of higher density may create features with an apparently simple bowl morphology, but with very complex surface irregularity superimposed. Other work [9] has shown that projectiles with a diameter less than 10 µm have a non-constant crater diameter/projectile diameter ratio. Due to this sub 10-micron non-linearity in crater depth/projectile diameter ratio, micron sized complex craters on Stardust foils may give an indication of how many impact features are being erroneously identified as due to a larger single impactor. Accordingly, in future work we intend to simulate the effects of varying internal grain size and porosity (hence bulk density) within silicate particles of a fixed overall grain size, to explore the potential of this very useful tool in the interpretation of cometary dust structure.

References: [1] ANSYS Inc., http://www.ansys.com/ (accessed Jan. 2009). [2] Brownlee D.E. et al., (2006) *Science, 314,* 1711-1716. [3] Hörz F. et al. (2006) *Science, 314,* 1716-1719 [4] Kearsley A.T. et al (2008) *MAPS* [5] Kearsley A.T. et al. (2008) *Int. J. Impact Eng*., *35*, 1616-1624. [6] Kearsley A.T. et al. (2006) *MAPS.,* 41, 167-180. [7] Leitner J. et al. (2008), *MAPS., 43,* 161-185. [8] Kearsley A.T. et al. (2009) *LPSC XXXX*, #1517. [9] Price M. C. et al. (2009) *LPSC XXXX*, #1564.