ASTEX MICROGRAVITY EXPERIMENT: SIMULATING ASTEROID REGOLITHS. N. Murdoch[1,2], B. Rozitis[2], P. Michel[1], W. Losert[3], T-L. de Lophem and S. F. Green[2]. [1]University of Nice-Sophia Antipolis, Observatoire de la Côte d'Azur (Laboratoire Cassiopee, BP 4229, 06304 Nice Cedex 4, France) [2]The Open University, PSSRI (Walton Hall, Milton Keynes, MK7 6AA, UK) [3]Institute for Physical Science and Technology, and Department of Physics (University of Maryland, College Park, Maryland 20742, USA)

Introduction: Despite their very low surface gravities, asteroids exhibit a number of different geological processes involving granular matter. Understanding the mechanical response of this granular material subject to external forces in microgravity conditions is vital to the design of a successful asteroid sub-surface sampling mechanism, and in the interpretation of the fascinating geology on an asteroid.

To date two space missions have characterised an asteroid in detail: the NEAR Shoemaker mission to (433) Eros, and the Hayabusa sample return mission to (25143) Itokawa. NEAR revealed a substantial regolith covering Eros [1], and Hayabusa revealed Itokawa to be a rubble pile asteroid (essentially made of regolith throughout) [2]. A dichotomy of rough and smooth surfaces was also observed at Itokawa including evidence of varied particle size and grain size sorting.

Space agencies are planning sample return missions, other than the current Hayabusa mission, to near Earth asteroids to bring back to Earth a pristine sample of an asteroid surface. These missions aim to investigate early Solar System processes by applying the vast array of laboratory analytical tools to these samples, to link meteorite classes to asteroid classes, and study components (such as interstellar grains, organics and volatiles) that do not survive the atmospheric entry or terrestrial contamination of meteorites.

However, due to the increased importance of inter-particle dynamics in a microgravity environment typical at an asteroid surface, the regolith may respond differently to analogous regolith on Earth. Therefore a sampling mechanism designed to work in a 1 g environment on Earth may not necessarily work in a lower gravity environment encountered at an asteroid.

Granular Systems: The state of a granular system is characterized by density, granular temperature, pressure and angle of friction. Recent research has shown that the direction of prior shear influences how granular matter starts to flow [3]. The implication is that regions that normally do not move under steady shear, move significantly during reversal of the shear direction. Studying the reversal of shear in a granular material can shed light on different modes of deformation that are evident when granular material is sheared in different directions.

Applying these experimental results to asteroids indicates that the dynamics of granular materials on their surfaces could also depend on the direction of

shear that they have undergone. For instance impact phenomena [4][5], tidal forces from planetary encounters [6], and YORP spin up [7] could apply shear forces to the surface. Therefore, their surface materials may not necessarily behave as classically as expected.

The AstEx Experiment: The AstEx experiment, entitled 'Simulating Asteroidal Regoliths: Implications for Geology and Sample Return', flew in the ESA 51st Microgravity Research Campaign in November 2009 as part of ESA's 'Fly your Thesis' progam.

The aim of the experiment is to characterise the response of granular material to rotational shear forces in a microgravity environment. A particular emphasis has been put on investigating the timescales to reach steady state flow and the memory effects of sheared glass beads in a Taylor-Couette shear cell in microgravity. The Taylor-Couette geometry is shown in Figure 1.
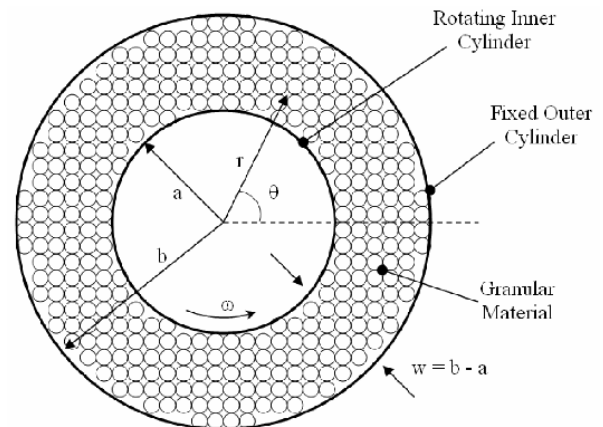

Figure 1 : The Taylor-Couette Geometry [8]. (a = Inner Cylinder Radius, b = Outer Cylinder Radius, w = Width of Shear Region, r = Radial Distance, θ = Angular Distance, ω = Inner Cylinder Rotation Rate)

There are two concentric cylinders. The outer cylinder is fixed and its inside surface is rough with a layer of glued on particles, the outer surface of the inner cylinder is also rough but it is free to rotate, and the floor between the two cylinders is smooth and fixed in place. The gap between the two cylinders is filled with granular material on which the rotating inner cylinder applies shear stresses. Large velocity gradients are then produced near the inner cylinder as the energy input in to the granular system by the rotating

inner cylinder is dissipated by friction in a narrow band. This localised region of shearing is known as a shear band. The size of the gap between the two cylinders is ~30 d where d is the average diameter of particles filling the gap. The full experiment hardware is shown in Figures 2 and 3.
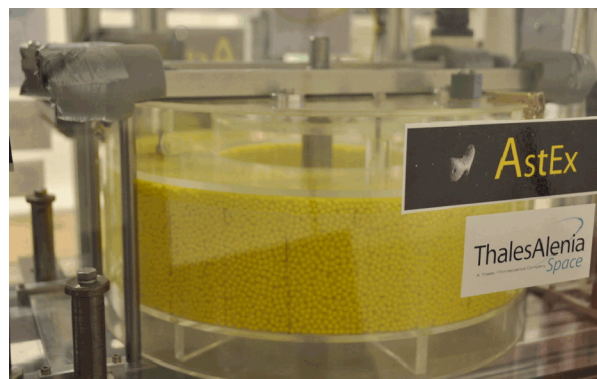

Figure 2: The AstEx Taylor-Couette shear cell filled with 4mm diameter glass beads.
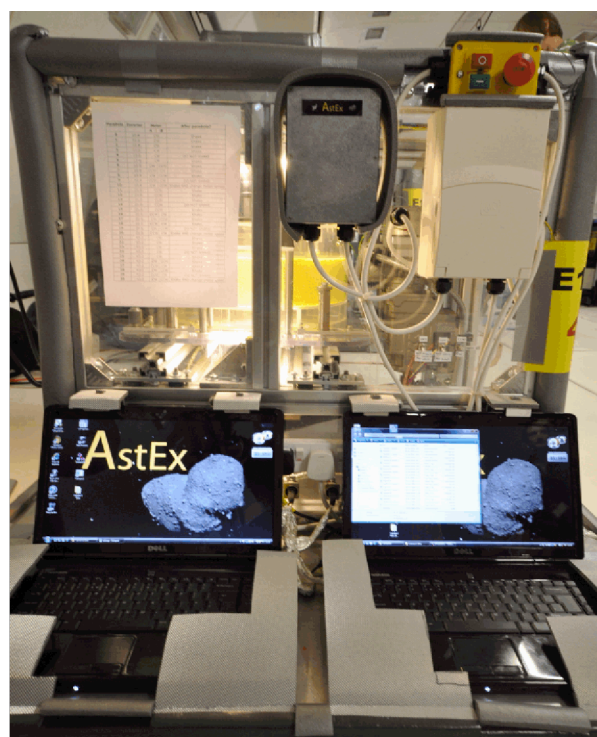

Figure 3: The full AstEx Experimental hardware in flight mode.

AstEx Experimental Method: The nominal gravity regime during a parabola consists of 1.8 g for 20 secs, 0 ± 0.05 g for 22 secs and 1.8 g for 20 secs, where g is the Earth's gravity. During the period of microgravity in a single parabola a granular flow was initiated by applying rotational shear forces to the granular material. High speed cameras (~60 fps) imaged the flow of the top and bottom layers of glass beads. Once a steady state flow was achieved particles continued to be imaged for the duration of microgravity.

After the flight the individual particles on the surface layers of the granular material were tracked using a particle tracking algorithm [9] so that their velocities could be determined. By calculating the particle velocities, it is possible to determine the timescales involved in initiating a steady state flow in a granular material. These timescales can then be compared to Earth based results.

Another investigation considers the effect of reversing the direction of shear on the steady state flow already started in microgravity. These three investigations (time to start a steady state flow, monitoring the flow, and effect of shear reversal on the flow) were repeated with granular materials of different particle sizes (3mm and 4mm diameter), and with different shear rates (4, 8 and 16 mHz) to determine the effect of these variables. In some parabolas experiments were also conducted in the 1.8 g regimes giving data for three gravity conditions (1 , 0 and 1.8 g).

Experimental Results: Since the AstEx microgravity experiments were completed in November 2009, there was not enough time to perform the full analysis of their outcomes at the time of preparation of this abstract. However, preliminary results indicate that prior shear direction is an important factor in the dynamics of granular materials in a microgravity regime and more detailed analysis will be caried out and presented at the conference.

References: [1] M. S. Robinson *et al.* (2002) *Meteoritics & Planet. Sci.,* 37, 1651-1684. [2] A. Fujiwara *et al.* (2006), *Science, 312,* 1330-1334. [3] M. Toiya *et al.* (2004), *Phy. Rev. Letters, 93,* 8, 088001. [4] P. Paolicchi *et al.* (2002) *Asteroids III*, 517-526. [5] K. Holsapple *et al.* (2002) *Asteroids III,* 443-462. [6] W. F. Bottke and H. J. Melosh (1996), *Nature, 381*:51-53. [7] W. F. Bottke *et al.* (2002), *Asteroids III,* 395-408. [8] M. Toiya (2006), *http://hdl.handle.net/1903/3886.* [9] D. Blair and E. Dufresne, *http://physics.georgetown.edu/matlab/*