CATASTROPHIC DISRUPTION OF MIXED ICE:SAND BODIES. A. Lightwing[1] and M. J. Burchell[1], [1]Centre for Astrophysics and Planetary Sciences, School of Physical Sciences, Ingram Building, University of Kent, Canterbury, Kent CT2 7NH, United Kingdom. M.J.Burchell@kent.ac.uk

Introduction: Impact driven catastrophic disruption of Solar System bodies is an important evolutionary driver for the size distributions of bodies found today. The recent discoveries of more and more Pluto sized bodies (not just small Edgeworth Kuiper belt objects but bodies comparable in size to Pluto itself, e.g. Sedna, Quaoar etc.) indicates that as a class the smaller icy planetary bodies are the most frequent class of planetary body in this Solar System (assuming one accepts them as planets). Although there is a large volume of space in the outer solar system, the large number of small bodies predicted out there means that these bodies will be subject to collisions from smaller bodies [1] at speeds of a few km s^{-1} [2]. Indeed it is interesting to note the recent report that Pluto has 3 observable satellites and not just one (Charon), indicating that there are still many interesting bodies to be discovered in that part of the Solar System.

Experimental studies of the energy needed to disrupt targets have long been carried out. Since laboratory scales are much smaller than those of real bodies in space, the results have to be scaled to larger sizes and combined with the energy need to disperse a shattered body against gravitational re-assembly. Nevertheless a knowledge of the critical energy for disruption at one scale (the laboratory) is a fixed point that can be obtained.

Although an increasing number of studies of disruption have looked at ice targets, few have considered mixed ice: sand targets. Since the bulk density of Pluto is estimated to be 2000 kg m^{-3}, with 60-70% rocky materials and the remainder ices (mostly water ice), it is not immediately obvious that data from disruption of pure ice targets is relevant. Thus in this work we have carried out a set of impact experiments on ice: sand targets with a bulk density of 1800 kg m^{-3} and approximately 80% sand to 20% water ice. In our experiments, for simplicity, we have a uniform mix of sand and ice. It is of course suspected that Pluto will be a differentiated body (i.e. rocky core, icy surface layer) although this has not yet been demonstrated.

Experimental Method: The two stage light gas gun of the University of Kent was used in this work [3]. The ice targets were made by cold water and sand and rapidly freezing. This provided targets with minimum porosity and uniform mixture of sand and ice throughout. The targets were then left in a freezer at 255 K for 4 days before use. We have also experimented with making targets with lower concentrations of sand, but in these the sand settles out non-uniformly in the frozen target. Accordingly we have used the method of mixing crushed ice, sand and water to make 50:50 sand: ice mixture targets. But, whilst uniform in their distribution of sand, these targets are slightly porous and so results from them are not included here (as porosity also influences disruption energies [4, 5, 6]).

The targets were not spheres (due to practical issues with moulds) but were instead squat cylinders (mass typically 740 g) with a diameter equal to their height. During each shot a flat face of the cylinder was used as the target face. Impacts were at normal incidence on the centre of this face. The projectiles were copper spheres, either 1 or 2 mm diameter. The projectile diameter was varied from shot to shot along with the impact speed to provide a range of impact energies. The projectile speed was measured in each shot to better than 1%. The impact energy was divided by the target mass to give the impact energy density Q (J kg^{-1}) for each impact.

If the result of an impact were a crater, the crater depth, diameter and volume were measured. If the result was a disrupted target, the masses of all largest fragments were obtained along with their largest linear dimensions.

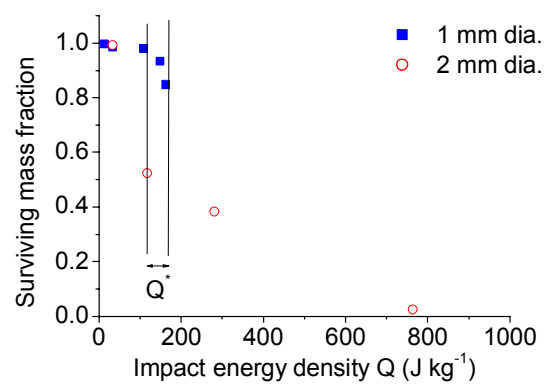

Figure 1: Variation of surviving mass fraction with impact energy density. Projectile dia. as shown.

Results: Nine successful impact experiments were carried out. Impact speeds ranged from 1.2 - 7.3 km s^{-1} and the energy density (Q) from 14 to 763 J kg^{-1}. The ratio of the mass of the largest fragment after

impact /original target mass is shown on Figure 1 vs. Q. For low Q values (where cratering obtained) the target mass after impact was used as the largest fragment mass.

As is usual in such experiments, there is a rapid fall in the surviving mass fraction as a critical energy density (Q*) is reached. This marks the transition from cratering to disruption. The value of Q at which the surviving mass fraction is found to be 0.5 is taken as Q*. Here, there is a slight range of possible values as there is some scatter in the data, but the range of values for Q* lies between 120 and 160 J kg^{-1}.

Discussion: Previous work has also looked at catastrophic disruption of ices in the laboratory. For solid ice, using the same light gas gun and projectiles, it was found that $4.9 < Q^* < 9.0$ J kg^{-1} [4]. This is significantly lower than that found here for the sand:ice mixture. The data from [4] are shown in Figure 2 along with the data from the current work. There is a clear difference in the two data sets. There is a factor of 20 difference in the disruption energies (Q*), with the mixed targets being harder to disrupt.

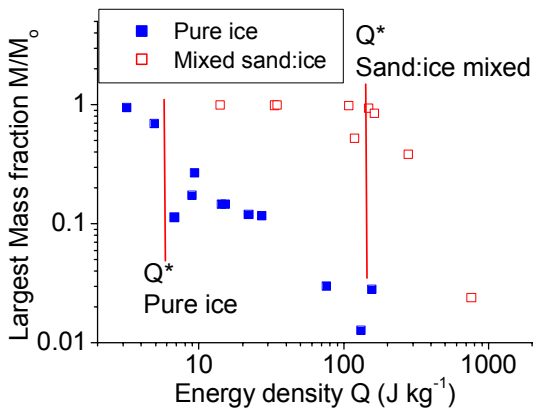

Figure 2: Comparison of data from the current work with that from [4] for impacts on solid ice.

At lower speeds (150 – 670 m s^{-1}) the impact strength (i.e. Q*) has been determined for pure ice and ice: silicate mixed targets by other researchers [5, 6]. They used pyrophylite and serpentine powers as the silicates in their targets in 50:50 ice : silicate mixtures. They found that for zero porosity targets, the Q* increased from 21 J kg^{-1} (pure ice) to 124 J kg^{-1} (silicate: ice targets). Thus although there are differences between the two experimental methods, the same general result is obtained, namely that adding the silicates to the ice increases the impact strength significantly.

Conclusions: We have carried out a study of how high speed impacts (km s^{-1}) can disrupt icy bodies. A significant influence on impact strength is found to be the presence of silicates in the icy target at levels compatible with the bulk density of Pluto. Ignoring any scaling issues this will make it harder to shatter a Pluto class object in the outer Solar System compared to a pure ice body. If mean impact speeds are fixed by orbital mechanics, then an increase of 20 in impact strength is equivalent to a similar increase in impactor mass, and of some 2.7 in the radius of an impactor required for disruption. This will significantly prolong the lifetime of a Pluto class body against being shattered in an impact and for example may be significant in predicting fluxes necessary to have caused the presence of a large, probably impact related satellite orbiting Pluto.

References: [1] Stern A. and Mitton J. (2005) Pluto and Charon, pub. Wiley. [2] Dell'Oro A., et al. (2001) *Astron. & Astrophys.*, *366*, 1053 - 1060. [3] Burchell M. J et al. (1999) *Meas. Sci. Technol.*, *10*, 41 – 50. [4] Dawe W., et al. (2005) *LPS XXXVII*, Abstract 1096. [5] Arakawa A., et al. (2002) *Icarus, 158*, 516 – 531. [6] Arakawa A., et al. (2004) *Icarus, 170*, 193 – 201.