MODEL DEVELOPMENT FOR ASSESSMENT OF THERMAL HISTORIES OF RETURNED STARDUST COMETARY DUST SAMPLES. W. W. Anderson and F. J. Cherne, Los Alamos National Laboratory, Los Alamos, NM 87545.

Introduction: The successful collection and return of cometary material by the Stardust mission has provided the astromaterials analysis community with an important source of samples with known provenance. However, the collection process of impact into silica aerogels at 6.1 km/s subjected the collected particles to shock pressures of a few to a few tens of kilobars, and to shocked aerogel temperatures of several thousand K. To maximize the value of the analytical data, thermal histories seen by the particles during capture must be known. The collection process leaves behind a record, in the form of the track in the aerogel collection material. We are developing a model of the collection process that can be used to invert observables such as track morphology and the size and gross composition of recovered particles to obtain temperature histories of collected particles. These thermal histories will aid interpretation of analysis results, allowing element and light isotope fractionation and structure alteration to be assessed and accounted for in interpretation of the analytical data.

Material Model for Collector Aerogels: The extreme states accessed during the collection process and the disparate lengthscales that must be accurately treated make development of the full model a difficult and highly complex task. As an initial step, we are concentrating on development of more detailed material models than currently exist. The most fundamental parts of the material model for aerogel are accurate shock compression and post-shock thermal parameters.

The most detailed dynamic material model for aerogel available is that of Anderson [1]. However, a substantial new set of data for shock wave response and thermal behavior is now available and allows significant improvement of the existing models.

Dynamic compression behavior. We have chosen to treat the shock wave in the aerogel explicitly, so that we need an accurate representation of the Hugoniot of aerogel. Since the aerogel collectors had variable initial densities, this Hugoniot representation should be valid for a wide range of starting densities.

At very low stresses, aerogel exhibits elastic response, eventually terminated by plastic yielding and the onset of irreversibly densification. Properties in the elastic region can be obtained from zero-pressure sound speeds and compression data [2,3]. The zero-pressure longitudinal sound speed is independent of initial density below ρ_{00} = 0.101 g/cm^3, with C_L = 0.08 km/s. At higher densities, the sound speed is adequately expressed by

$$C_L = -0.128 + 1.923\rho_{00}$$

Above the plastic yield stress, the isothermal bulk modulus of the aerogel appears to be strictly dependent only on the present density and described by the Murnaghan equation:

$$K = K_0\left(\frac{V_0}{V}\right)^m$$

with K_0 = 0.7 MPa, V_0 = 7.83 cm^3/g, and m = 3.25 [9].

At shock-induced material velocities above ~1.3 km/s, the temperature of shocked aerogel approaches and exceeds the glass temperature of silica, resulting in different behavior of the deviatoric stresses in shocked aerogel. A number of data for the Hugoniot of aerogel at high velocities are available [4,5,6,7,8,9]. Usually, the shock velocity is written as a polynomial in the shock-induced particle velocity:

$$U_s = C_0 + su_p + qu_p^2 + wu_p^3$$

The current data allow the following fits for the coefficients:

$$C_0 = 0$$
$$s = 1.391 - 3.84\rho_0 + 6.25\rho_0^2$$
$$q = -0.087 + 0.85\rho_0 - 0.87\rho_0^2$$
$$w = 0.00569 - 0.0365\rho_0$$

for densities in g/cm^3 and velocities in km/s.

Thermal model of shocked aerogel. The thermal model of shocked aerogel must account for heat deposition and must also include the effects of bond breakage and ionization. The previous model , in which the shock temperature was estimated by

$$T \approx T_0 + \frac{E_H - E_b e^{-E_b/E_H}}{C_V}$$

where E_b is the energy of the Si-O bond in silica and E_H is the internal energy increase due to shock compression, and C_V is the constant volume specific heat, assumed to be $3R/\mu$ where μ is the mean atomic mass.

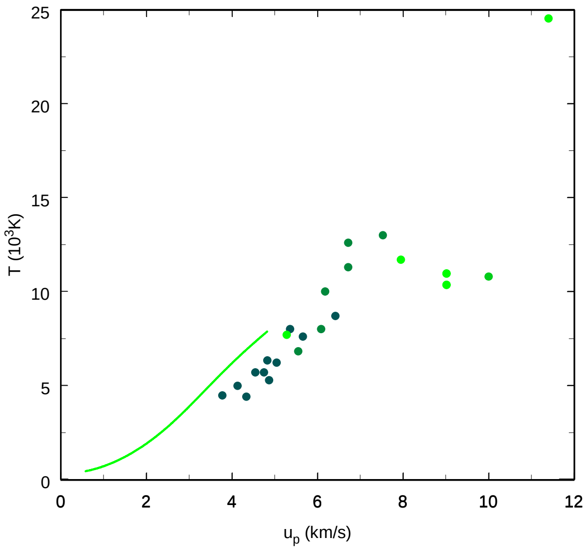

Figure 1. Hugoniot temperature data [4,7,8] and results of previous model for shock temperature.

As seen in figure 1, this model overestimates the shock temperature of aerogel.

Results of New Material Descriptions in Previous Model: The original penetration model of Anderson [1] can readily incorporate the improved material descriptions presented here. It can also be modified to account for the smoothly graded density profiles of the flight aerogels. To obtain preliminary information on the consequences of using the improved model, we conducted a series of calculations of particle impacts into aerogel.

Comparison with laboratory experiments. First, we consider a test, compared to data from Hörz et al. [10]. The experiments used 50 μm glass spheres launched at aerogel with a density of 0.02 g/cm^3. Because the model of Anderson ignores particle ablation and viscosity effects, we expect the penetration depth to be overestimated. As seen in Figure 2, this is indeed the case. In the present case, this is an indication that the temperature history should be contracted by ~20% in time.

Calculation for stardust encounter conditions. Using a representative density profile provided by S. Jones [11], we have conducted simulations of 1 and 10 μm forsterite particles into a collector at 6.1 km/s. Scaling the time duration by 80% as suggested above, we obtain the temperature histories presented in figure 3. Although the model is still very crude at this point, we do obtain an important bound on the thermal history seen by such a particle during capture. It should be noted that the temperatures presented are those of the shocked aerogel. The full model will require thermal transport to be considered to obtain estimates of the

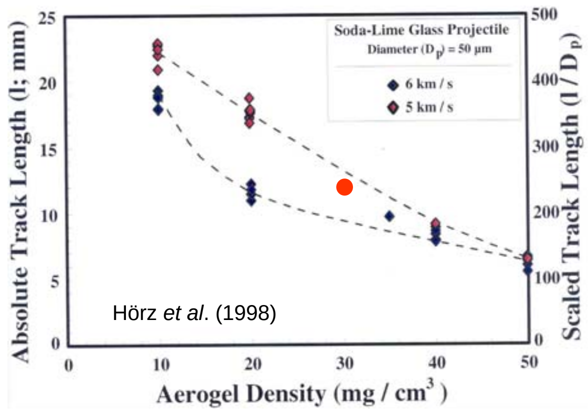

Figure 2. Results of improved Anderson model, compared to experimental data.

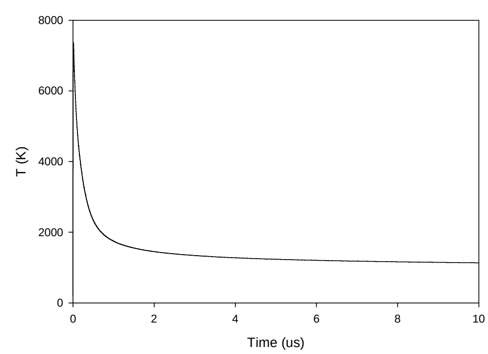

Figure 3. Temperature history of a 10 microm forsterite particle.

temperatures of the particles themselves. However, we do see that the potential exists for significant thermal alteration of some particles, especially those with significant relatively volatile components.

References: [1] Anderson W. W. (1998) NASA/CR-1998-207766. [2] Gibiat V. et al. (1995) *J. Non-Cryst. Solids* 186, 244-255. [3] Scherer G. W. et al. (1995) *J. Non-Cryst. Solids* 186, 316-320. [4] Holmes N. C. et al. (1984) *Appl Phys. Lett.* 45, 625-628. [5] Holmes N. C. and See E. F. (1992) *Shock Compression of Condensed Matter 1991*, 91-94. [6] Rabie R. and Dick J. J. (1992) *Shock Compression of Condensed Matter 1991*, 97-90. [7] Nikolaev D. N. et al. (2000) *Shock Compression of Condensed Matter—1999*, 121-124. [8] Fortov V. E. et al. (2003) *Mod. Phys. Lett. A* 45, 1835-1840. [9] Knudson M. D. et al. (2005) *J. Appl. Phys.* 97, 1-14. [10] Hörz F. et al. [11] Jones, S., (2005) Pers. Comm.

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