WHAT WAS THE THERMAL HISTORY OF COMETARY DUST PARTICULES DURING THEIR COLLECT BY THE NASA'S STARDUST SPACECRAFT? M. Roskosz[1], H. C. Watson[2] and H. Leroux[1]; [1]LSPES, Université des sciences et technologies de Lille, Bât. C6, 59655, Villeneuve d'Ascq, France (mathieu.roskosz@univ-lille1.fr); [2]Lawrence Livermore National Laboratory, Earth and Environment, 7000 East Avenue L-206, Livermore CA 94550, USA.

Introduction Cometary dust particles are considered relicts of pristine materials that accreted to form primitive meteorites and eventually planets. Compared to other small primitive objects of the solar system, cometary grains are poorly known. In this respect, the first sample return of cometary materials, the Stardust mission, raised considerable expectations from astrophysicists, geologists and cosmochemists.

The Stardust mission was a plain success but still had to face inherent problems related to the collection of samples itself. The grains were captured from the 81P/Wild 2 comet tail at a relative velocity of 6.1 km/s in a low density silica aerogel medium. During this hypervelocity impact, flash heating of dusts could not be avoided. This thermal event may hinder detailed understanding of dust mineralogy and geochemistry because the parameters of this flash heating are not well constrained.

Models and experiments tend to indicate a high peak temperature, strong thermal gradients and a very fast quench (within a few microseconds). In this study we estimate the parameters of the flash heating based on the interdiffusion of MgO and SiO_2 between molten MgO-rich cometary dust particles and the embedding molten aerogel.

Analytical and data-processing methods: The sample was studied by analytical Transmission Electron Microscopy (ATEM). We used a Tecnai G2-20 twin (LaB_6 filament) operating at 200 kV. Specimens were mounted on a beryllium low-background holder. The microstructure was obtained by bright/dark field imaging. Chemical compositions were measured using Energy Dispersive X-ray Spectroscopy (EDS) with an EDAX Si-detector with ultrathin window. We used probes size ranging from 5 to 10 nm. For quantitative analyses, calculations of element concentrations and atomic ratios were carried out using calibrated k-factors and thin film matrix correction procedures. This setup was particularly useful to measure concentration profiles at the grain-aerogel interface.

These concentration profiles were then processed in order to extract quantitative information on the thermal history of the grain (see below). A finite difference model for diffusion in two immiscible phases undergoing cooling was employed with no flux boundaries on each end to account for the effects of impingement from nearby melt droplets. Concentration and temperature dependent MgO and SiO_2 diffusion coefficients were used in the model, and the partitioning behaviour at the interface was determined from the MgO-SiO_2 phase diagram.

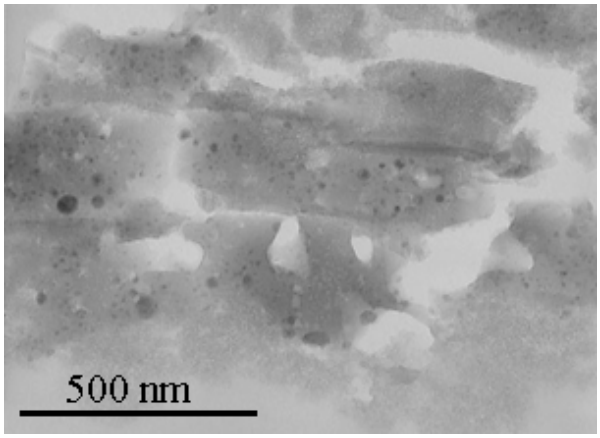

Figure 1: TEM bright field image showing the general microstructure of the sample. The microstructure consists of a silica-rich glassy matrix containing nanometer beads of Fe-Ni-S phases and vesicles.

Results: An overview of the mineralogy of cometary dust particles collected during the Stardust mission was recently published [1, 2]. To quantify one of the highest grade of thermal alteration recorded by Stardust samples, we focused on a highly thermally modified sample, labelled C2044,2,41,3,6. (see [3] for a detailed description of the sample). The typical microstructure of such grains consists of a vesicular silica-rich glassy matrix containing Fe-Ni-S nanophases (Fig. 1). Silicate pockets occasionally outline ghost mineral assemblages. They are visible only with chemical EDS maps (Fig. 2). In the following we focus only on Mg-rich ghost minerals which are free of Fe-Ni-S nanophases. They should originate for enstatite or forsterite.

Turning now to compositional results, we first note that the Mg-rich patches and the adjacent molten aerogel do not have pristine compositions. The 'ghost minerals' have a MgO concentration below the stoichiometry of enstatite, typically 30 mol %, while a significant MgO content is measured in the aerogel (typically 5 mol. % of MgO). This result implies that after the collection and the melting of the grain and its surrounding aerogel, MgO and/or SiO_2 diffused across

the molten grain/molten aerogel interface. In this respect, composition profiles across the interface reveal a composition gradient in the MgO-rich side (Fig. 3). Its shape, and more particularly the horn-like shape in the MgO-rich side, is typical of the cooling of two immiscible liquids. This is due to the presence of a miscibility gap in the MgO-SiO_2 binary system, which precludes full mixing of the Mg-rich melt and the surrounding melted aerogel. For this reason, we used the persistence of the melt pockets and ghost minerals, the extent of the contamination of the silica matrix by MgO and the shape of the diffusion profile to shed light on the thermal history of cometary dust particles collected by the spacecraft.

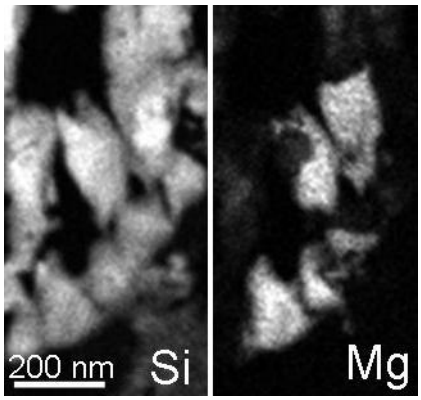

Figure 2: Elemental distribution for Si and Mg showing the presence of Mg-rich areas, free of Fe-Ni-S nanophases, in contact with almost pure silica areas (molten aerogel). The composition profiles were measured at the MgO and SiO_2-rich interfaces.

First, compositions of the two coexisting glasses far from the interface record the temperature at which the two liquids reached their equilibrium compositions (Fig. 3). Based on the MgO-SiO_2 phase diagram, an average temperature of 2075 K is obtained. This peak temperature is the 'characteristic' temperature from which the dust was quenched from a thermal equilibrium. The time required for the two melts to attain equilibrium at the characteristic temperature was calculated by using an isothermal diffusion model.

Second, the MgO enrichment of the MgO-rich liquid close to the interface is characteristic of the cooling rate that prevailed during the quench of the two immiscible liquids (Fig. 3), due to the evolution of the MgO concentration along the branch of the miscibility gap. The best calculated fit cooling rates were of within the range $20\text{-}100.10^6$ $K.s^{-1}$.

Discussion: The most unexpected result is the time scale deduced from the main composition profile. It is more than an order of magnitude longer than values generally assumed. From the initial liquid state, the dust was heated for at least 0.1 ms when the quench is generally thought to occur in less than 10 μs. Our measurements demonstrate that the capture in aerogel generated a relatively high peak temperature, that persists for a substantial period of time. This result is particularly important because for a micron-sized cometary dust, even a tenth of a millisecond is a long enough time over which considerable modifications may occur.

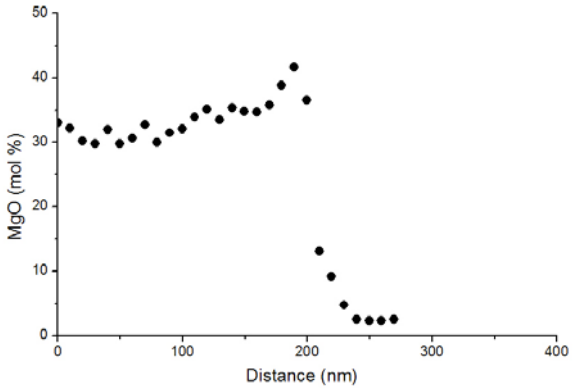

Figure 3: Concentration profile across the grain-aerogel interface.

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References: [1] Brownlee D. et al. (2006). *Science* 314: 1711–171. [2] Zolensky M. E. et al. (2006). *Science* 314: 1735–1739. [3] Leroux H. et al. (2008) *Meteoritics & Planet. Sci., in press.*