A THERMOLUMINESCENCE STUDY OF SEMARKONA CHONDRITE: AN APPLICATION ON DETERMINATION OF METAMORPHIC HISTORY OF STARDUST PARTICLES.

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Introduction: The historic return of dust particles from a comet by the Stardust spacecraft presents a unique opportunity to examine a highly important kind of primitive solar system material that has not been previously available. The goal of the Stardust mission was to return both particle samples from Comet Wild 2 and from interplanetary dust particles (IDP's). It is believed that cometary material has been relatively unaltered since the formation of the solar system (when the comets, themselves formed) and so represents the building blocks of the early solar system and our neighboring local stellar medium. IDP's are believed to be similar to material derived from comets and asteroids [1,2] and thus will provide useful comparisons. However, we do not know the origin of the IDPs and these particles have suffered alteration due to atmospheric passage.

Here we use data for chondrules separated from primitive meteorites to argue that thermoluminescence studies will yield important new insights into the origin and history of particles recovered by Stardust and that such measurements are feasible.

Samples and Experimental Procedure: Data were taken from Sears et al [3] where full details can be found. Briefly, chondrules and matrix fragments were hand-picked from Semarkona and other primitive ordinary chondrites. The TL apparatus was a Daybreak Nuclear and Medical Inc. system and irradiations were performed with a 250 mCi 90Sr β source. Bulk samples of the Dhajala chondrite were used for standardization and for checking daily and long-term stability the apparatus.

Results and Feasibility of the Measurements: Figure 1 shows the TL sensitivity – the TL produced after removable of the natural TL and after the administration of a test dose – as a function of mass. Natural TL intensities for extraterrestrial materials are usually 10-100 times higher than sensitivities. Our chondrules ranged in mass from about 1 mg to ~10 µg and the TL sensitivity ranged from ~10 to ~10^{-5} (on a scale where bulk Dhajala = 1) [3]. Sears et al. [3,4] performed a detailed mineralogical and petrographic study of these chondrules. While most contained noncrystalline materials – or glass and fine crystallites – Allegan chondrules were entirely crystalline. The Allegan chondrules thus define a TL-mass line for crystalline materials which reaches the detection limit for TL sensitivity at a mass of 10^{-7} mg, or a particle of only a few µm in size. The other words, providing the Stardust particles are at least partially crystalline TL measurements are easily possible on Stardust grains that are commonly 10 – 100 µm. Early observations suggest that the Stardust particles contain crystalline material [5].

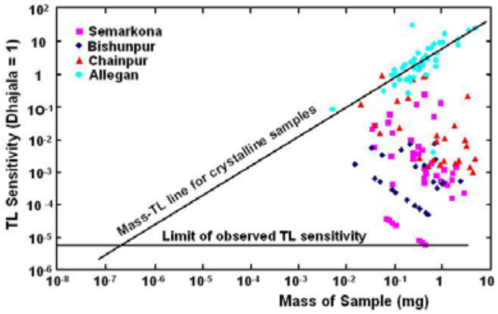

Figure 1. *The study of separated chondrules from ordinary chondrites suggest that it should be possible to detect a signal from Stardust crystalline particles larger than a few µm.*

Discussion: Natural TL and TL sensitivity provide very different information on the origin and history of solar system materials. The level of natural TL observed in a sample is the result of a competition between build up due to radiation exposure and decay due to thermal drainage [6]. The ratio of the natural TL level observed to the saturated TL value (the maximum value possible) is a function of radiation dose rate and temperature:

$$\frac{\phi}{\phi_s} = \frac{1}{1 + [\, s / \alpha R \exp(-E/kT) \,]} \qquad (1)$$

where ϕ (Gy, 100 Gy = 1 rad, a unit of absorbed dose) is the level of natural TL, ϕ_s (Gy) is the value of TL at saturation, dimensionless parameter s is the Arrhenius factor, α is the rate constant (s^{-1}) for de-excitation, R is the dose rate (Gy/s), E is the trap depth (eV), k is Boltzman's constant (eV/K) and T (K) is temperature.

In the context of a particle emerging from the surface and interior of a comet nucleus, and collected by a passing spacecraft, particles resting on the surface (or near surface, say within a meter) will have experienced high radiation levels and high temperatures, while buried samples will have experienced lower temperatures and lower radiation levels. By sorting particles into one of four categories, it will be possible to gain insight into the movement of particles through the upper meter or so of the nucleus and the extent of recycling of particles in the upper layers of the comet nucleus. Of course, heating events overprinted on the entire collection of particles (say heating during atmospheric passage or soakback after landing) would be apparent in uniform natural TL throughout the collection.

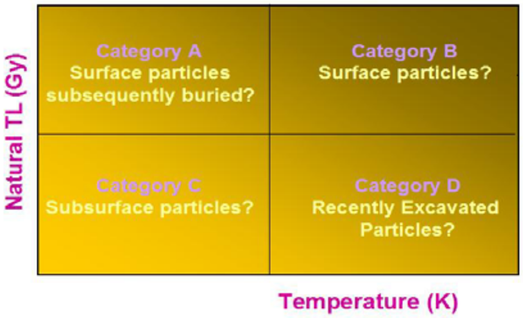

Figure 2. *Particles resting on the surface (or near surface, say within a meter) will have experienced high radiation levels and high temperatures (Category B), while buried samples will have experienced lower temperatures and lower radiation levels (Category C). However, TL adjusts much faster to temperature changes than it does to changes in radiation environment, so we also expect to observe particles in Categories A and D above.*

In contrast, induced TL measurements to extraterrestrial samples provide unique insights into metamorphic history, probably the most notable being the petrographic classification of type 3 (or unequilibrated) ordinary chondrites. This application of induced TL has withstood the test of nearly 30 years [4]. However, measurements of induced TL for a wide variety of extraterrestrial materials, CO [7], and CV [8] chondrites, and HED meteorites [9], have all yielded interesting results.

The value of induced TL measurements is mainly that the technique is able to resolve metamorphic differences with very high resolution. It usually does this by detecting the amount of the mineral responsible for the TL signal which is being formed somehow during metamorphism, often through the crystallization of primary glass.

The shape of the glow curve, the indiced TL signal as a function of heating temperature during readout, also provides information on the mineralogy of the phosphor which might not otherwise be readily. Glow curve trends in CAI that were due to mineralogical changes induced by metamorphism. Similarly low-temperature feldspar has an induced TL glow very different from that of high-temperature feldspar (the former is a sharper peak at lower glow curve temperatures) so that a plot of peak temperaure again width is a means of readily identifying grains with high and low tempetarure metamorphic histories. Grains not plotting in the high or low fields do not contain feldspar as their dominent luminescence mineral (Fig. 3).

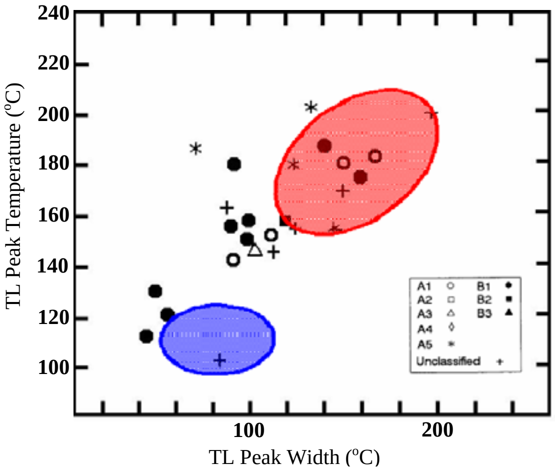

Figure 3. *The peak temperature and the peak width for the induced TL glow curve [3] enables chondrules of Semarkona chondrite to be sorted into those with a low (blue) and high (red) temperature metamorphic history (plotting in the low and high fields respectively) and those that are essentially unmetamorphised and for which feldspar is not sufficiently abundant to obscure the signal from other minerals. This is the case only with the very lowest levels of metamorphism, say <300 °C.*

Conclusion: Natural and induced thermoluminscence measurements on Stardust grains are feasible and have the potential to provide unique information on radiation history and metamorphism experienced by the grains.

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