GEMS AND INTERSTELLAR SILICATE GRAINS; J. P. Bradley, MVA Inc., 5500/200 Oakbrook Parkway, Norcross, GA 30093.

A recent paper has described a population of submicrometer-sized "amorphous silicate" grains (GEMS) which are ubiquitous among the fine-grained matrices of some interplanetary dust particles (IDPs) [1]. (GEMS is an acronym for Glass with Embedded Metal and Sulfides).
Although GEMS could have formed in the Solar System, it is argued (by [1]) that they are most likely preserved interstellar grains for the following reasons. (1) GEMS are abundant in cometary IDPs. (2) They appear to have suffered prolonged exposure to ionizing radiation. (3) The exposure occurred *prior to* accretion of the IDPs in which they reside. (4) The physical properties of GEMS are similar to those of interstellar (silicate) grains (as inferred from astronomical observations). If the interstellar origin hypothesis for GEMS is correct, then (a) interstellar dust is available for routine collection in the stratosphere using U2 aircraft and, (b) it is possible to recognize some interstellar components in primitive meteoritic materials based on chemical anomalies.

Unlike the rare, refractory interstellar grains that are extracted from meteorites, GEMS contain reactive minerals like glass and nanometer-sized α-Fe(kamacite) crystals . Therefore, it is unlikely that they could survive even the relatively mild conditions of parent body alteration that have altered the matrices of (chemically) primitive carbonaceous chondrites. GEMS are abundant only in the matrices of chondritic porous (CP) IDPs, which is consistent with the observation that this class of IDPs appear to have suffered little if any parent body alteration. While CP IDPs may be derived from more than one source (e.g. comets and primitive outer asteroids), those IDPs so far identified as being of cometary origin all belong to the CP subset [2,3]. Additional evidence for a cometary origin is suggested by the submicrometer-scale distribution of Mg/Mg+Fe in CP IDPs, which corresponds closely to the Mg/Mg+Fe distribution in comet Halley's dust [4,5]. (Other IDPs and the fine-grained matrices of primitive meteorites, on the other hand, are unlike Halley on a submicrometer scale). Comets are believed to contain the largest reservoir of unaltered interstellar grains in the Solar System [6,7], and submicrometer-sized "amorphous silicate" grains are a major components of contemporary interstellar dust (see below).

Two strategies are being employed to further constrain the possible sources of GEMS. The first is to compare the properties of GEMS with those of contemporary interstellar grains, and the second is to attempt to synthesize GEMS in the laboratory. Information about the properties of interstellar grains is derived from observations of absorption, scattering, polarization, as well as depletions of elements from the gas phase onto grains [8]. From these observations, multiple theories have been developed regarding interstellar grains, but most acknowledge that silicates and hydrogenated carbon are major components. There are various hypotheses regarding the relationship between these two components (e.g. silicate cores with carbonaceous mantles [9]). Silicates are known to be abundant in part because infrared spectra from interstellar sources show a pronounced absorption feature around 10 µm corresponding to the Si-O stretch mode in silicates. The shape of this silicate feature suggests that the grains are predominantly amorphous or glass-like [12,13]. The average size of the grains (determined from extinction) is between 0.1 and 0.5 µm with a steep fall-off in the numbers of grains smaller than 0.1 µm and larger than 1 µm [14]. The bulk composition of interstellar dust, inferred from interstellar gas-phase depletions, is approximately chondritic for most of the major rock-forming elements [10,11].

Polarization is perhaps the most curious effect of interstellar dust. Since the amount of polarization is correlated with the infrared silicate feature, the aligned grains are believed to be absorbing silicates [8,15,16]. Many mechanisms have been proposed to explain alignment of grains in the galactic magnetic field [17], but the central problem confronting each mechanism is that the strength of the field required to align dielectric silicate grains exceeds observed interstellar magnetic field strengths by at least a factor of 10. To overcome this difficulty, Jones and Spitzer [18] predicted that silicate grains containing nanometer-sized inclusions of ferromagnetic or paramagnetic materials (e.g. α-Fe or Fe_3O_4) will be "superparamagnetic" , i.e. they will have a paramagnetic susceptibility up to 10^6 times the usual value. Mathis [19] and others conclude that superparamagnetic inclusions provide the most plausible explanation for the alignment of (dielectric) interstellar silicate grains in the galactic magnetic field [20,21].

The GEM synthesis experiments consist of exposing various mineral mixtures (e.g. sulfides and silicates) to protons (and alpha particles) over a range of energies and fluences. A preliminary irradiation experiment using 20 KeV protons has demonstrated that some of the chemical and structural properties of GEMS can be duplicated in the laboratory [1]. In the forthcoming experiments, attempts will be made to synthesize microgram to milligram quantities of GEMS, with the aim of accumulating a sufficient mass of (α-Fe containing) GEMS to experimentally demonstrate low-temperature superparamagnetism in GEMS. (Superparamagnetic behavior has been demonstrated experimentally in nanometer-sized α-Fe particles in the temperature range 5 -100^{o}K [22]). At the same time, effects such as depth of radiation damage (amorphization), recoil mixing, and enrichment/depletion profiles of specific elements will be evaluated. The experiments should provide insight into the flux regime(s) in which GEMS were formed and they may further constrain the environment(s) of formation of GEMS.

In summary, the properties of GEMS have been shaped by exposure to ionizing radiation. GEMS are fundamental building blocks of cometary IDPs and they bear an uncanny resemblance to interstellar silicates. Most contemporary interstellar silicate grains are 0.1-1 μm diameter "amorphous" silicates, their bulk compositions are probably approximately chondritic, and they may contain nanometer-sized superparamagnetic inclusions (e.g. α-Fe). Most GEMS are 0.2 -0.5 μm diameter "amorphous" silicates, their bulk compositions are approximately chondritic (for all major elements except carbon), and they contain nanometer-sized superparamagnetic α-Fe (kamacite) inclusions.

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