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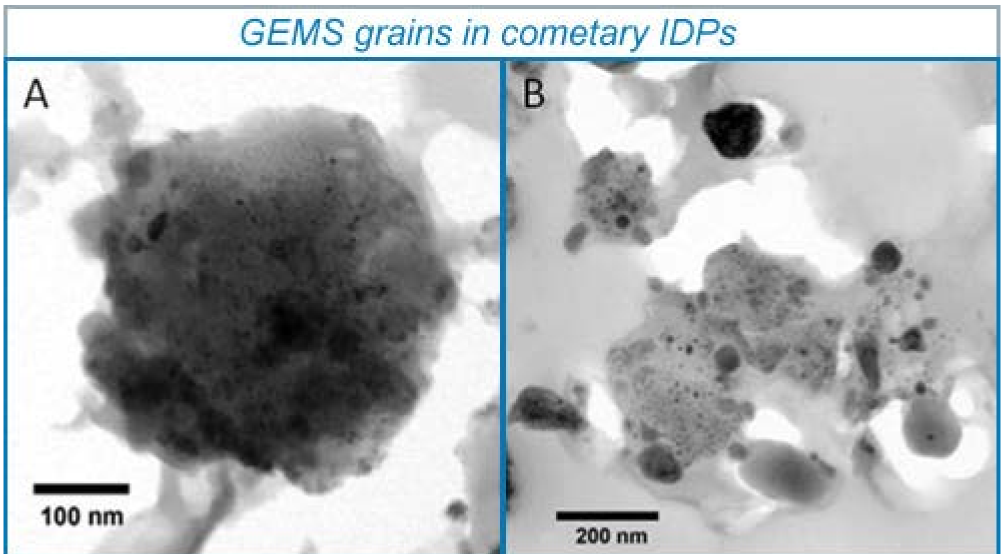
Cosmochemical Building Blocks called GEMS

GEMS, an acronym for glass with embedded metal and sulfides, was coined in 1994 by John Bradley (Lawrence Livermore National Laboratory) for the already well-documented grains found in large quantities in the type of interplanetary dust particles (IDPs) linked to cometary sources. Typically just 0.1-0.5 micrometers in diameter, GEMS grains are made of nanometer-sized sub-grains of kamacite (FeNi metal) and Fe-Ni sulfide in a Mg-Fe-Al amorphous silicate matrix. They are still a hot topic, decades later, because GEMS grains are so abundant in cometary IDPs, represent important cosmochemical building blocks, and can be explored by increasingly advanced analytical devices and techniques. Solving the origin of these tiny, amorphous silicate grains has been compared to forensic detective work at the nanometer scale! A consensus opinion about their origin has not been reached.



(From Keller and Messenger, 2011, On the Origins of GEMS Grains, *Geochimica et Cosmochimica Acta*, v. 75, p. 5336–5365, doi:10.1016/j.gca.2011.06.040.)

Above: [A] Rounded GEMS grain with dark inclusions of FeNi metal and Fe sulfides. [B] Cluster of GEMS grains held together with carbonaceous material. Both are bright-field transmission electron microscope images.

Chemical and isotopic analyses on GEMS grains, as well as laboratory experiments that synthesize amorphous silicates, are being conducted to help establish how and where GEMS grains formed. There are two main schools of thought on how to interpret the data, with the crux of the debate being a presolar versus solar nebula origin. The debate is fueled, in part, by the sub-micrometer size of GEMS grains, which is near the limit of isotopic measurements.

The presolar-origin hypothesis says GEMS grains began as free-floating, crystalline mineral grains that were exposed to ionizing radiation in the interstellar medium (ISM). In this scenario, endorsed by Bradley and colleagues, the grains were chemically and isotopically homogenized by prolonged sputtering and redeposition during irradiation processing before being swept into the cloud of dust and gas from which our Solar System formed. Bradley and colleagues have found embedded relict grains, such as pyrrhotite (FeS) and forsterite ($MgSiO_4$), inside some GEMS grains, which they interpret as remnants of the original crystals from which they formed. If GEMS grains are presolar, then they would meet the benchmark that establishes a presolar origin: Nonsolar oxygen isotopic composition. While some GEMS grains meet this benchmark (a few percent of the total analyzed so far and all notably larger in size than average), all the rest have oxygen isotopic compositions within the range of Solar System materials. Bradley and colleagues argue that the evidence of presolar origin was erased; most GEMS grains were so extensively irradiated, modified, and homogenized in the ISM that they no longer retain their original, nonsolar isotopic compositions.

The solar nebula-origin hypothesis says GEMS grains are Solar System products that formed as late-stage non-equilibrium condensates. Lindsay Keller and Scott Messenger (NASA Johnson Space Center) argue GEMS grains display enormous chemical variability, which is inconsistent with the idea of chemical homogenization. They say the observed heterogeneities point to non-equilibrium conditions during grain formation and may reflect the changing composition of the gas from which they condensed. They suggest that if there are relict core grains, they were a base for the accumulation of material either through simple aggregation or, possibly, as condensation nuclei. While Keller and Messenger agree that a small percentage of GEMS grains are surviving presolar grains based on nonsolar oxygen isotopic compositions, they contend the overwhelming solar isotopic compositions indicate a solar nebula origin. They also suggest GEMS grains have complementary compositions to the crystalline silicate components in IDPs and perhaps they all formed from the same reservoir in the inner Solar System before being transported out to the comet forming region.

The research seems to be showing GEMS grains in IDPs have chemical and isotopic properties that reflect both presolar and Solar System origins. Experiments to synthesize amorphous silicates and analyze their structural and electronic properties are underway in Bradley's laboratory, which will add to the growing body of data regarding GEMS grains. The story continues to unfold as further studies will allow a deeper appreciation of these abundant silicate grains and what they have to tell us about ancient stardust, processes in the solar nebula, and the very beginnings of our Solar System.

See:

» Bradley, J. P. (1994) Chemically Anomalous, Preaccretionally Irradiated Grains in Interplanetary Dust from Comets, *Science,* v. 265, p. 925-929, doi:10.1126/science.265.5174.925 [***NASA ADS entry***].

» Bradley, J. P. (2011) Investigation of Atomic and Electronic Structure of Primitive and Synthesized Amorphous Silicated Using High-Resolution Electron Energy-Loss Spectroscopy (HREELS), *Workshop on Formation of the First Solids in the Solar System*, Nov. 7-9, 2011, Kaua'i, Hawai'i [***Abstract***].

» Keller, L. P. and Messenger, S. (2011) On the Origins of GEMS Grains, *Geochimica et Cosmochimica Acta,* v. 75, p. 5336-5365, doi:10.1016/j.gca.2011.06.040 [***NASA ADS entry***].

» ***Presolar Grain Database***, with isotopic data for over 10,000 presolar grains, hosted by Washington University in St. Louis.

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