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Earth & Space

To See a World in a Grain of Interplanetary Dust

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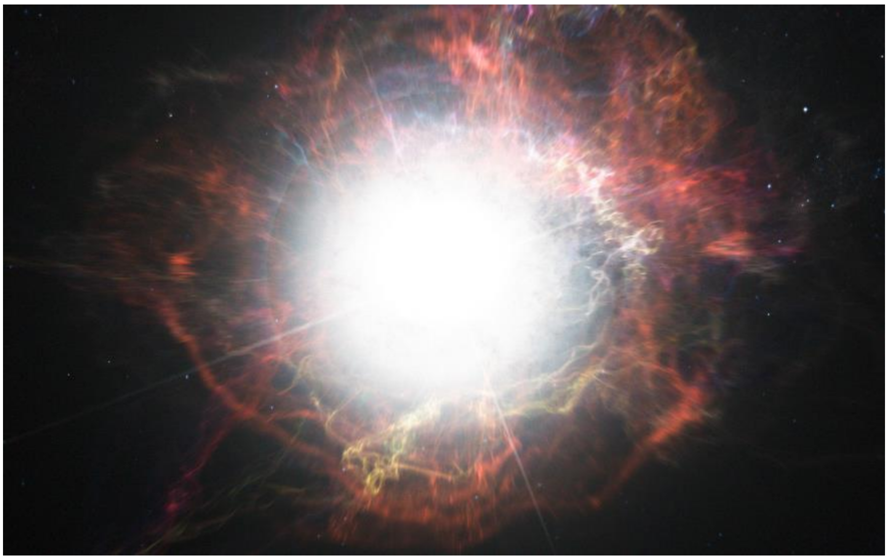
ABSTRACT

Interplanetary dust from comets contains surviving interstellar dust, the starting solids from which our Solar System formed. In some, we find evidence of the first aggregation of dust in a cold environment, the initial step in planet formation.



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With each new spacecraft launch, we become more familiar with today's Solar System, from our nearest neighbor planets to those in cold and distant outer orbits, yet the details of how the Solar System formed and evolved to its present state remain a mystery. We know that our Sun and planets were formed from interstellar dust and gas, ejected by older stars during their lifetimes and deaths, but it is unclear how much of that original interstellar dust has survived into the present day. It is always a challenge to reconstruct what happened in the past – like paleontologists trying to figure out how an extinct animal looked from its fossilized bones – but fortunately, there are some small bodies that have not changed much since the formation of the planets. Icy comets act as frozen time capsules holding the starting materials from which larger planetary bodies formed and evolved. Because they stayed small, comets didn't experience as much heating and changes to the materials in their interiors as planets did.

By studying the dust released by comets as their ices sublime, we can actually see for ourselves the earliest inventory of building blocks from which our own world formed. This dust travels through interplanetary space, and some reaches orbits that cross the Earth's. Interplanetary dust particles settle down through Earth's atmosphere and are collected by high-flying NASA aircraft in the stratosphere before they can descend into the far dirtier lower layers of the atmosphere and get lost in the multitude of Earth dust. These particles often contain a high abundance of tiny amorphous silicate grains called GEMS, for "glass embedded with metal and sulfides". GEMS have many properties consistent with interstellar dust that has been beaten, broken up and reformed by supernova explosions that send massive shock waves traveling through interstellar space. Some GEMS have isotope compositions that confirm that they began as dust grains ejected from stars before the birth of our Sun. It has long been debated, however, whether all GEMS are interstellar dust that survived Solar System formation; Some scientists argue that most GEMS condensed from gases in the hot inner Solar System while other scientists argue GEMS formed in cold environments in the interstellar medium like the cloud from which our Solar System formed. By observing how GEMS and carbon-based organic materials are interwoven, we have been able to address this debate and expose details of the earliest stages of planet formation.

In a [transmission electron microscope]() that uses electrons to image and analyze materials down to the scale of individual atoms, we studied very thin slices of interplanetary dust particles. We mapped the elements making up the particles and studied the chemistry in the organic materials. In this way, we found that some well-preserved GEMS in comet dust contain subgrains that are coated with organic material and that those organic coatings have slightly different chemistry than the organic matrix that glues larger components together into interplanetary dust particles.

Aggregation of smaller particles to form larger clumps of material is a key process in the formation of planets. The subgrains in GEMS represent the very first generation of solids that aggregated together and the first baby step towards planet formation. Because the organic coatings on the subgrains decompose at low temperatures, GEMS cannot have aggregated in the hot inner Solar System. Instead, they likely aggregated in the cloud of dust and gas from which our Solar System formed. The sticking together of many GEMS and larger components with the organic matrix "glue" to form the interplanetary dust particle represents a subsequent step towards planet formation.

Our observations mean that GEMS are likely made of surviving interstellar dust grains that were the original building blocks of planetary systems. One interesting implication is that tiny bits of interstellar dust carried in interplanetary dust particles, the leftovers of planet formation, are continuously raining down on planet Earth. Indeed, each full-grown head of lettuce is likely to contain at least one interplanetary dust particle among the other Earth particles on it. We found that some GEMS grains have experienced more alteration and processing, some of it due to frictional heating as their host interplanetary dust particle enters Earth's atmosphere. We continue to search for better-preserved ancient comet materials from the birth of our Solar System – like paleontologists looking for a more complete fossil to better reconstruct that now-extinct animal. Hopefully, in the near future, a spacecraft mission will return cryogenically-frozen comet samples to Earth that will be our best-preserved fossils yet.