PRESOLAR GRAINS OF STAR DUST: ASTRONOMY STUDIED WITH MICROSCOPES

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Traditionally our knowledge of stars, how they formed, and how they evolve has been obtained from astronomical observations using ground and orbit based telescopes. Such remote observations have revealed the condensation of small dust grains in the atmospheres of late evolutionary stage stars based on the absorption bands observed in the spectra of these objects. However, the complexity of interpreting astronomical spectra makes it difficult to determine molecular content, let alone information on chemical processes at sites of grain formation. Fortunately, it is now possible to study star dust directly using electron microscopes, revealing detailed information about dust formation and the conditions within the stellar sources from which these dust grains formed [1-4].

On a spiral arm of our Milkyway galaxy, a star in its final stages of evolution expanded into a red giant. In the outer atmosphere of this dying star, dust grains of nanometer (10^{-7} cm) to micron (10^{-4} cm) size condensed. Nearby, a massive star ended its life in a violent supernova explosion, expelling its gases in great outflows. As its gases expanded and cooled, small dust grains condensed. The death of massive stars results in the formation of star dust which is blown outward into interstellar space. There the dust mixes and combines with interstellar gas clouds. The gravitational collapse of one of these dust laden gas clouds (the solar nebula) formed our solar system. Much of the star dust in the solar nebula was reprocessed and its original form destroyed by the heat generated during gravitation collapse of the nebula. However, could some star dust survive in its pristine form and still be present in our solar system today? If so, where is it, and more importantly how do we recognize it?

Large bodies like the sun, the planets, and their moons all experienced temperatures sufficiently great to convert their accreted star dust to other forms. However, this was not the case for much smaller bodies. For instance, comets which are thought to be the most primitive objects in our solar system might contain grains of unaltered star dust. In addition, the least metamorphosed meteorites, carbonaceous chondrites, which have experienced only modest thermal alteration since their accretion could conceal surviving star dust. Fortunately, we have collected specimens of carbonaceous chondrites which have fallen to Earth as meteorites.

How does one know if a mineral grain in a meteorite is presolar in origin (i.e. formed before our solar system)? All elements heavier than helium are produced by stellar nucleosynthesis. Elements are defined by the number of protons in their nucleus, and each isotope of an element is defined by the number of neutrons in its nucleus. Different star types can produce different distributions of isotopes for a given element through stellar nucleosynthesis. For example, certain isotopes of xenon are only formed in supernovae and not in red-giant stars. In large solar system bodies, all accreted star dust was broken down, and their distinctly different isotopes were mixed together to form new minerals. Consequently, the isotope compositions of terrestrial rocks, lunar rocks, and meteorites are similar to the average composition of all isotopes present in the solar system. Therefore, if you find a mineral grain that has isotope compositions remarkably different from that of the average for our solar system, it must be presolar in origin. This is provided that these differences are anomalies that cannot be explained by natural processes that alter isotope compositions of minerals formed in the early solar system. Therefore, the identification of mineral grains as surviving presolar grains (i.e. star dust) is based on the presence of anomalous isotope compositions within the grains (see Fig. 1).

The two most abundant forms of presolar grains that have been found in primitive meteorites are nanometer-sized diamond [5] (Fig. 2) and submicron to micron sized SiC [6] (Fig. 1). In addition, presolar grains of graphite [7] (Fig. 3), carbide mineral solid solutions of Ti, V, Fe, Zr, Mo, and Ru [1, 2, 8] (Fig. 4), kamacite (FeNi) [8], corundum (Al_2O_3) [9], spinel ($MgAl_2O_4$) [10], titanium oxide [11], hibonite [12], and silicon nitride [13] have also been found in primitive meteorites. The isotopic compositions of these grains tell us about the processes of element nucleosynthesis in their source stars. The microstructure (crystal structure, lattice defects, intergrowths of several different mineral forms, etc.) of these grains tell us about the physical conditions (temperature, pressure, etc.) where the grains formed as well as how they formed. The study of stars is no longer restricted to gazing up through telescopes. Now, astronomy can be studied by looking down through powerful electron microscopes.

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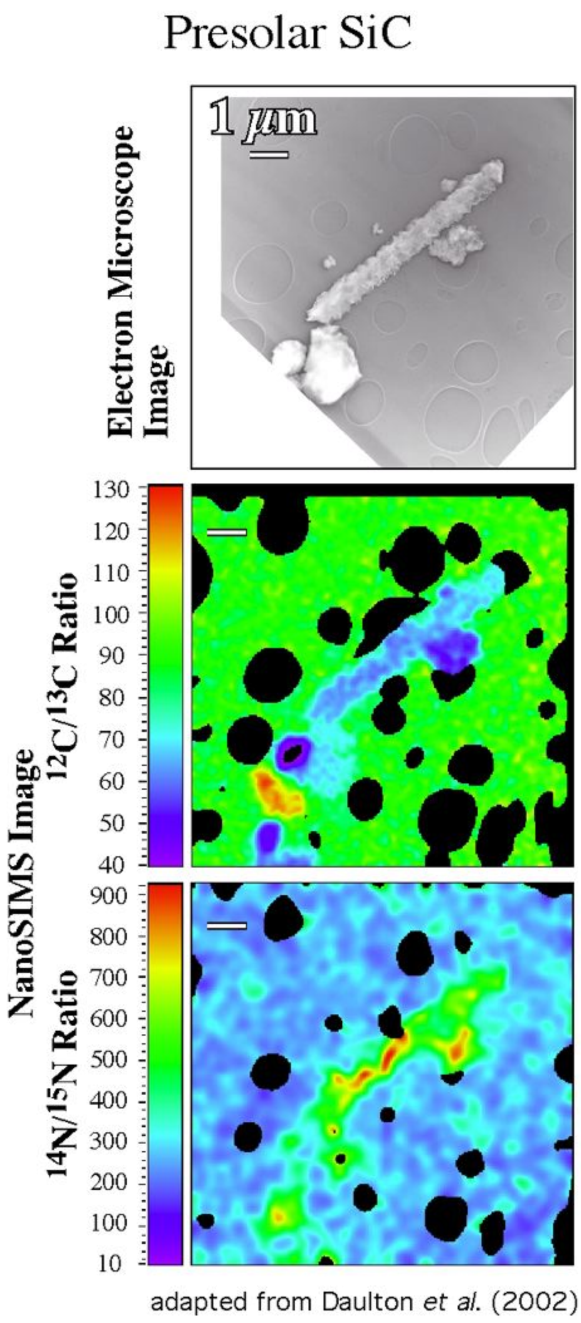
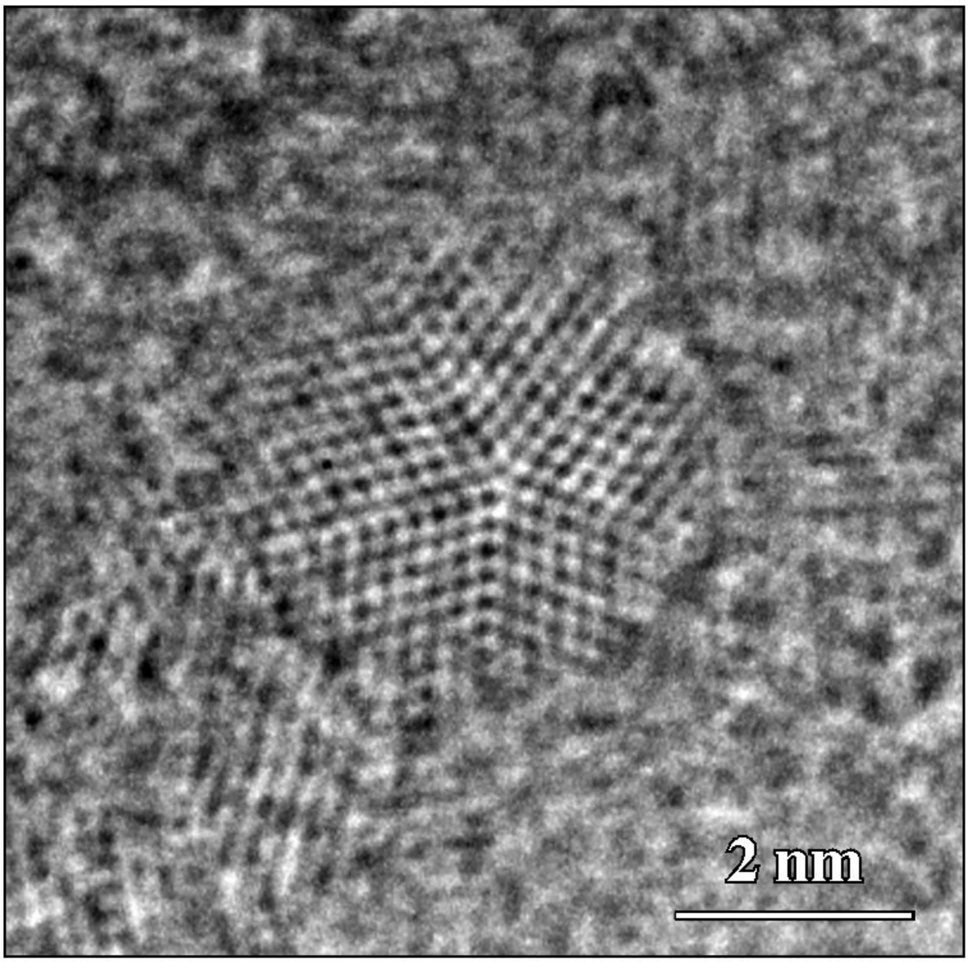

Presolar SiC
1 μm
Electron Microscope Image
NanoSIMS Image
12C/13C Ratio
130
120
110
100
90
80
70
60
50
40
14N/15N Ratio
900
800
700
600
500
400
300
200
100
10
adapted from Daulton et al. (2002)

Figure 1

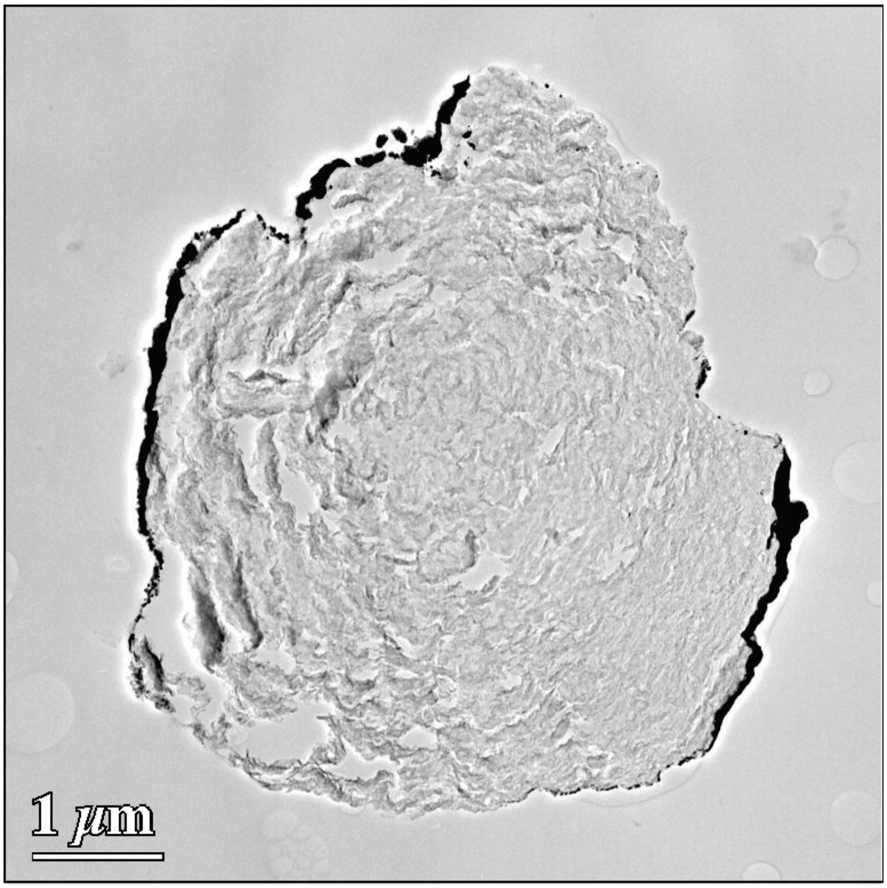
Presolar Diamond



adapted from Daulton *et al.* (1996)

Figure 2

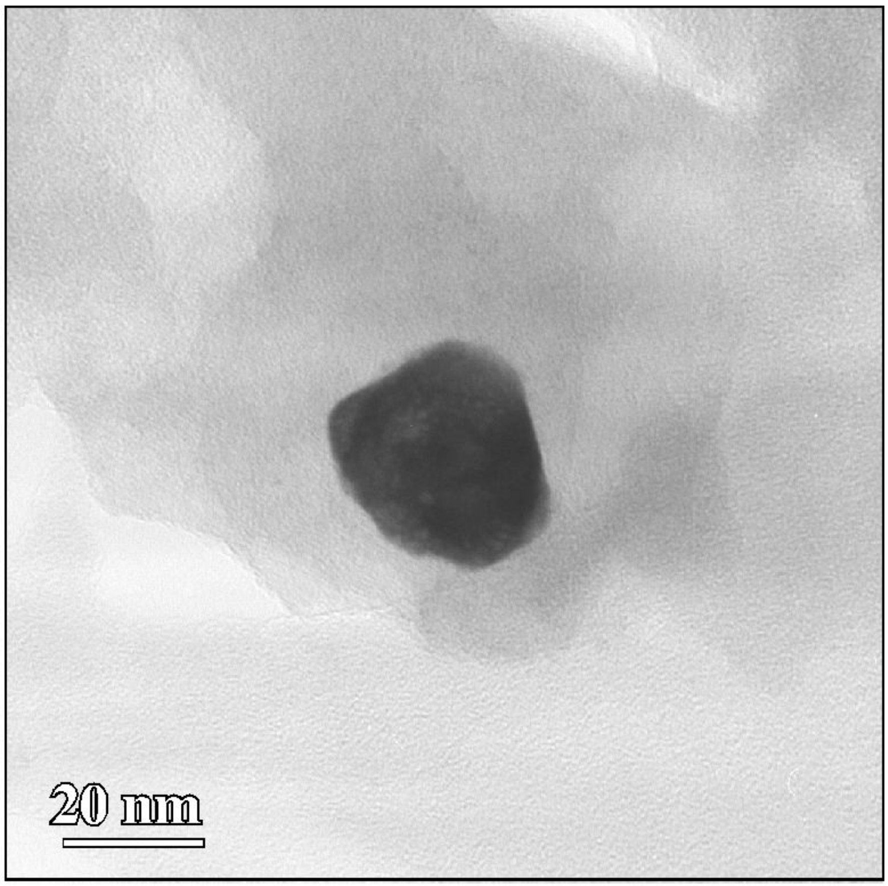
Sectioned Presolar Graphite Spheroid



Daulton, Croat, and Bernatowicz (2002)

Figure 3.

Presolar TiC entrapped within a
Presolar Graphite Spheroid (see Fig. 3)



Daulton, Croat, and Bernatowicz (2002)

Figure 4.