Electron Microscopy of Stardust

New Light Shed on a 40-Year-Old Astronomical Mystery

As reported in *Science*, researchers from Lawrence Livermore National Laboratory, NASA/Ames, and Washington University, working with the staff and facilities of LBNL's National Center for Electron Microscopy (NCEM) have used a new spectroscopic technique to deduce the chemical structure of an important component of interstellar dust grains.

Much of what is known about interstellar dust particles comes from astronomical observations of how they absorb and emit light. The strongest spectral signature from the interstellar medium in the ultraviolet portion of the electromagnetic spectrum is the so-called 2175 angstrom (Å) feature or "2175 Å bump." The feature has been enigmatic: its central wavelength is almost invariant, but its bandwidth varies from one line of sight to another, suggesting that it might be due to the presence of different materials (or the same material with variable properties). It was variously believed that the material(s) responsible for this signal might be either oxygen-rich (e.g., oxides or silicates) or carbon-rich (e.g., graphite or other organic compounds). However, the subject remained controversial and a number of exotic materials had been proposed, including nano-diamonds, fullerenes, carbon 'onions' and even interstellar organisms.

The key to solving this mystery lay in the careful direct study of the interplanetary dust particles. These particles, which can be gathered from the Earth's stratosphere, are complex collections of material from the primitive solar system and pre-solar grains from the interstellar medium. To characterize a given particle, a technique with superior spatial and spectral resolution was required. A new generation microscope for nanoscale high-resolution spectroscopy at NCEM was perfect for the job. This monochromated Tecnai microscope, the first of its type in the United States, provides 0.18eV resolution in the energy-loss spectrum obtained from a finely focused electron probe only a nanometer in diameter. This combination of spatial and spectral resolution is critical to many materials properties that depend on localized electronic structure, for example, in nanoparticles or defects. This microscope combines nanometer scale spatial resolution with the ability to perform high-resolution valence band electron emission spectroscopy (VEELS) in the same energy range as the ultraviolet energy range.

Using this technique, the researchers were able to show that certain carbon-based and amorphous silicate grains were indeed of extra-solar origin and produced the distinctive 2175 Å feature. Moreover, they were able to show that for carbon-rich interstellar grains, the 2175 Å feature becomes stronger with increasing oxygen content, suggesting that carbonyl species may be present. Amorphous silicates were known to be ubiquitous throughout interstellar space, but oxidized (carbonyl-containing) organic molecules had not before been identified unambiguously in the interstellar medium. The presence of both oxygen carriers—one silicate-based and the other carbon-based—may explain the variable bandwidth of the astronomical feature, with relative abundance or physical state of each component varying from one sight line to another.

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John Bradley, Zu Rong Dai, Rolf Erni, Nigel Browning, Giles Graham, Peter Weber, Julie Smith, Ian Hutcheon, Hope Ishii, Sasa Bajt, Christine Floss, Frank Stadermann, Scott Sandford, "An Astronomical 2175 Angstrom Feature in Interplanetary Dust Particles," Science 307, 244 (2005).

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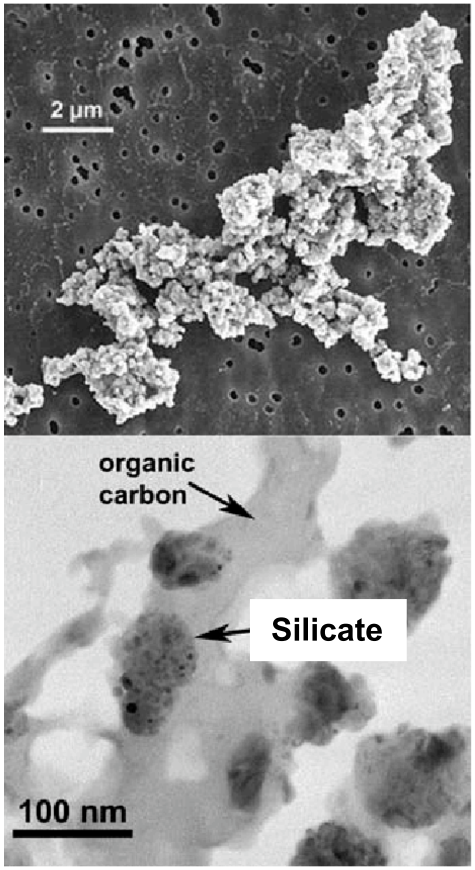
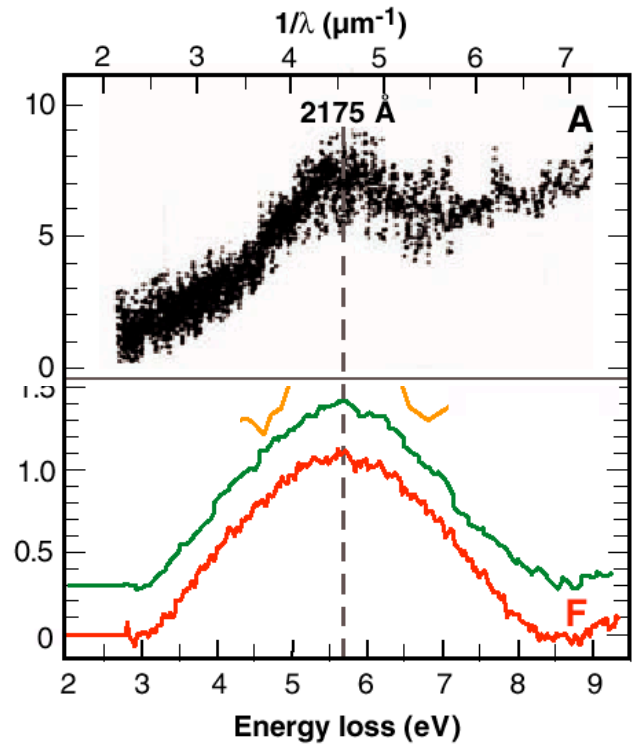


Scanning electron microscopy *(SEM) image of a typical interplanetary dust particle (above). These particles consist of a mixture of interplanetary and interstellar material. Transmission electron microscopy (TEM) image (below) indicates embedded regions within the particle that are either carbon-rich or silicate-rich due to interstellar material.*



An astronomical ultraviolet observation *of the 2175 angstrom feature (top). Valence band electron emission spectroscopy (VEELS) spectra (below), obtained from small carbon-rich (green) and silicate-rich (red) interstellar grains embedded in interplanetary dust particles. The results show that the 2175 angstrom feature can be due to both silicate and carbon-based material in the interstellar medium.*