Scientists Provide Evidence that Life on Earth May Have Come from Comets

Scientists have provided new evidence for the existence of iron sulfide – iron combined with sulfur – in comets, which are large chunks of ice and rock that have remained nearly unchanged since the beginning of the solar system. The catalytic behavior of iron sulfides is involved in the formation of hydrocarbons – key building blocks of life – so this discovery reinforces the idea that seeds of life may have come to Earth from comets. The results of the study are described in the May 9, 2002 issue of *Nature.*

"Sulfur is one of the more abundant elements in space," says Lindsay Keller, a scientist at NASA's Johnson Space Center (JSC) and lead author of the study, "yet astronomers have never been able to account for it around young stars – until now."

Two groups of scientists participated in the study. The first looked at dust particles coming from comets and falling in Earth's atmosphere. The second made astronomical observations of the disks of dust and gas surrounding young stars, and determined the chemical composition of these disks.

"When the solar system formed, the dust that was not swept up in the solar system ended up in comets," Keller says. "This dust has been sitting inside the icy comets for 4.5 billion years. So comets represent a sort of a freezer of presolar materials. By looking at the particles given off by comets, we can track down the particles that were present in the beginning of the solar system.

"Another way to understand how our solar system started to form is to look at disks of dust and gas around young stars," he adds. "What happens there is very similar to what is thought to have occurred in our solar system."

Cosmic vs. Earth Dust

Although the origin of comets is still uncertain, scientists believe that most reside outside the orbits of the planets in the Kuiper belt and Oort cloud. As a comet makes its way towards the sun, it releases dust and gases as the surface is warmed. A fraction of the dust that is released is swept up by the Earth.

"Because these particles are so small, many of them slow down in the upper atmosphere (at ~100 km altitude) without getting strongly heated – so they are not strongly altered – and they slowly settle over weeks to months on to the ground," Keller says, adding that the Earth accretes roughly 40,000 tons of interplanetary dust each year.

NASA has, for the past two decades, sent aircraft with special sticky collectors to altitudes of 12 to 14 miles to capture the cosmic dust as it falls through the stratosphere before it becomes mixed with Earth dust.

The collected dust particles, which are one-tenth the diameter of a human hair, are examined in the ultra-clean Cosmic Dust Laboratory at JSC.

"The dust particles are so tiny that they are invisible to the naked eye," Keller says, "so you need a microscope to see them and a very clean environment not to contaminate them with dust coming from the air."

Scientists wearing clean-room overalls – often called "bunny suits" – use high-resolution, light optical microscopes to examine the morphological characteristics and chemical composition of the par-

The inner solar system is suffused with a vast cloud of interplanetary dust. This dust cloud is invisible to the naked eye as the zodiacal light - a triangular glow rising above the horizon shortly after sunset or before sunrise. The picture to the right shows the zodiacal light together with comet Hale-Bopp. (Courtesy of Richard Wainscoat).

ticles carefully. The particles are then stored in dust-free, nitrogen-filled cabinets, which are available to other scientists for more detailed investigations.

Ultra-thin samples of dust

But the dust particles are so tiny that scientists cannot handle them easily. To investigate the chemical composition of some of the dust particles, Keller and his colleagues John Bradley, George Flynn and Don Brownlee surround the particles by beads of epoxy resin 10 to 20 times larger than the grains, thus making the beads easier to handle than the grains. "Having a dust grain inside an epoxy bead is like having a bug inside of an ice cube," Keller says.

Once the epoxy hardens, the scientists mount the bead on a sample-holding device called a microtome, which is a very finely-machined instrument that cuts the bead into extremely thin slices, the thickness of each slice being three thousandth of the bead's diameter. "Iron sulfide is a very dense and strongly absorbing mineral," Keller says, "so when the samples are that thin, you can finally get light through the sample."

The scientists determined the composition of the dust-containing slice by using two complementary techniques. The sample was first analyzed at JSC with a transmission electron microscope, in which electrons are sent through the sample to reveal its atomic structure and chemical composition. The slice of dust was also studied by using very intense light from beamlines U10B and X1A at the NSLS. By looking at how infrared light is absorbed in the samples, the scientists can determine what kinds of minerals and compounds are present in the particles.

Keller and his colleagues discovered that several of the dust particles were mainly made of iron sulfides. "When we looked at the infrared spectra, lo and behold, we had a very nice signal that corresponded exactly to iron sulfide," Keller says. Using very intense light was key to the detection of iron sulfide, he adds, because the samples are "so small and so thin" that the intensity generated by the sample is too weak to be detected by off-the-shelf lab instruments. "The infrared intensity in NSLS's VUV ring is about 500 – 1000 times brighter than conventional instruments, which translates into a much improved signal," he says.

Cosmic Dust Laboratory (CDL) at NASA JSC.

But more exciting results awaited Keller and his colleagues when they compared their results with those of another group of scientists looking at young stars trillions of miles away from Earth.

An unknown signal from the cosmos

What inspired Keller and his collaborators to analyze their particles were the results from astronomers studying the chemical composition of disks of dust and gas around two stars recently formed. The two balls of fire, called the Herbig stars, are surrounded by disks of dust and gas, which have not given birth to planets yet – if planets were to arise from the disks.

The scientists studied the two stars with the Infrared Space Observatory Observatory (ISO), an astronomical satellite that investigated the infrared light emitted by the dust and gas surrounding fledgling stars from 1995 to 1998.

The scientists, working at the Astronomical Institute in Amsterdam in The Netherlands, the European Space Agency in Noordwijk, The Netherlands, and the Astronomical Institute and University Observatory in Jena, Germany, identified many of the chemical elements present in the two stars. But, when they decided to remove from the stars' infrared spectra the contributions from all known elements, a signal of unknown origin appeared.

"When the astronomers subtracted everything from their spectra that they knew was there – the silicates, the glasses, the carbon, and ices – there was always a big residual feature," Keller says.

Iron sulfide revealed again

"The ISO scientists interpreted the signal incorrectly as being possibly due to iron oxide," Keller says. "In fact, our signal occurred at the same position on the spectra as their signal. It was a very nice match in terms of peak position, shape, and width."

After studying carefully their spectra, the two groups agreed that the "unknown" signal was indeed produced by iron sulfide. They also considered spectra of terrestrial samples known to contain iron sulfide and found that they also matched very well with their respective experimental spectra.

The researchers also found that their results agreed with predictions on the abundance of solid sulfur around young stars. "Astronomers have predicted that sulfur was all present as dust grains, not in the form of gas," Keller says. "Our results could account for the abundance of sulfur in the iron sulfide grains, as predicted."

Seeds of life?

By showing for the first time that iron sulfides are both present in comets and around young stars, Keller and his collaborators provide further evidence that "seeds of life," in the form of dust grains or hydrocarbon molecules, may have led to the development of life on Earth.

"Many of the current models for how Earth acquired early organic molecules are from particles that came out of space," Keller says. "So comets may have brought to Earth the chemicals that are necessary to life, such as organic molecules and water."

It is interesting to consider that "seeds of light" may have been pouring on Earth from the sky since Earth's creation. "I am fascinated to be working on grains of materials that are older than the solar system, "Keller says. "To realize that the accumulation of vast amounts of star dust that ended up forming our sun and the planets around it is just as fascinating."

BEAMLINE
U10B and X1A

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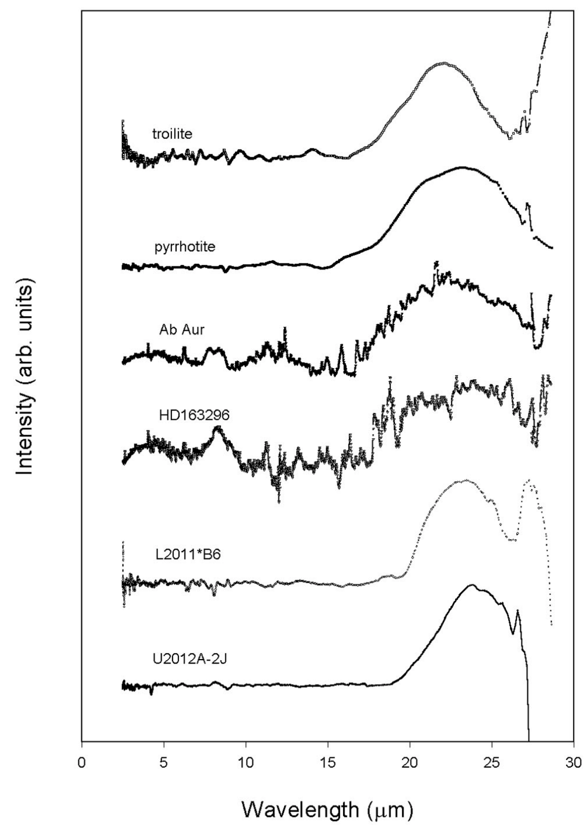

The first two spectra are from terrestrial standards, which are samples known to contain iron sulfide. The two spectra in the middle are from observations of young stars called the Herbig stars. In these spectra, the scientists have subtracted all the known components such as silicates, ices, and carbon from the original spectra. The bottom two spectra are from dust particles, found to be very rich in iron sulfide. All three types of spectra show a peak that is infrared active at the same wavelength. Keller and his collaborators show that the peak is due to iron sulfide, a chemical that was probably present during the early times of the solar system formation and may have sowed the seeds of life on Earth.