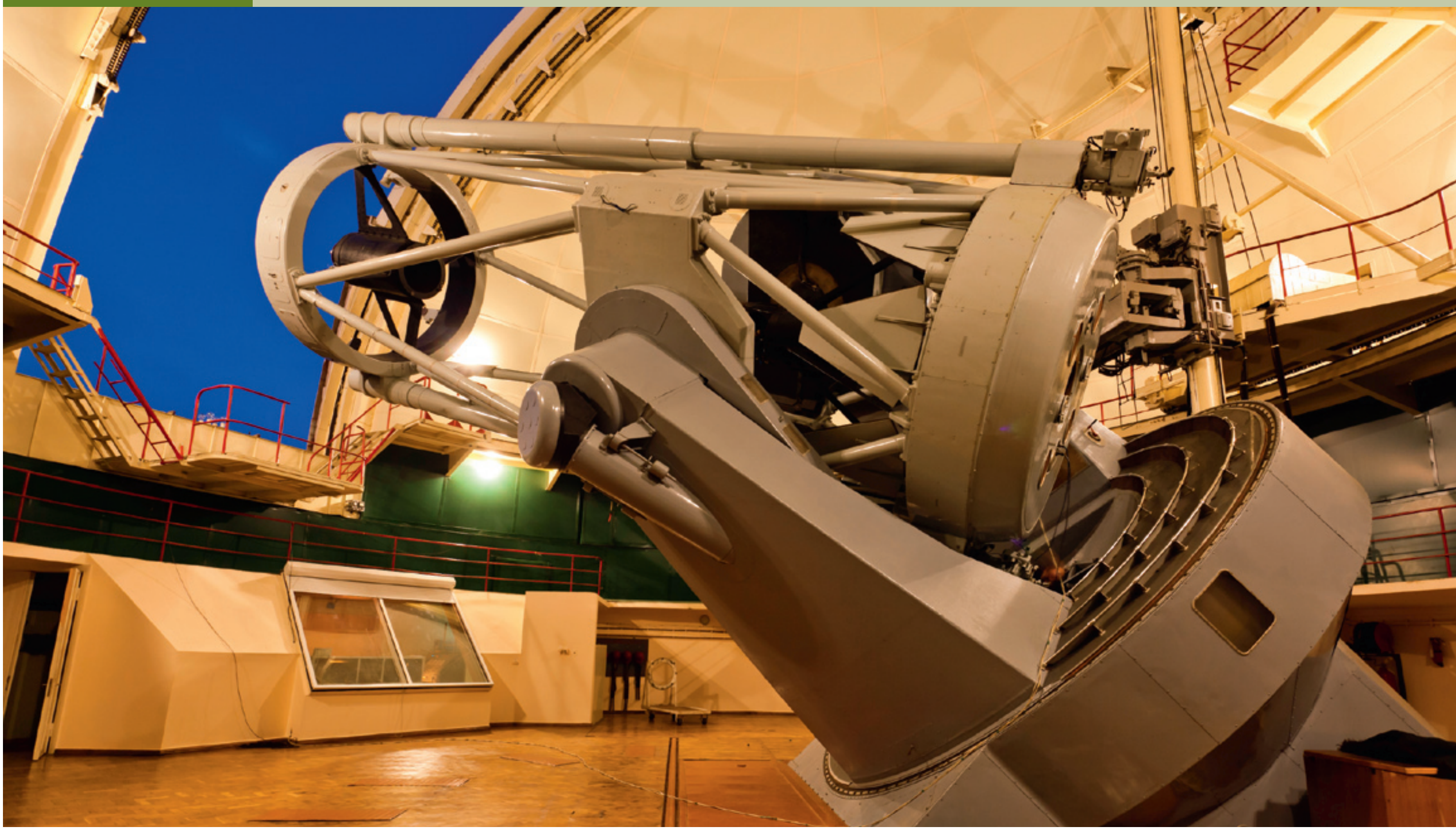
CASE STUDY

Infrared Microscopy



Matching FT-IR Microscopy to Infrared Telescopy Helps Unravel Earth's Mysteries

Summary

Astrophysicists have made dramatic strides in understanding the formation of the solar system by orbiting enormous Infrared (IR) telescopes that allow them to generate Infrared spectra from clouds of molecular dust that are in the process of forming stars and planets. A major challenge researchers face is that many of the IR spectra collected from the interstellar dust are not found anywhere on earth, making it impossible to identify the chemical composition of the dust. Dr. Andreas Morlok and colleagues at the Natural History Museum of London, United Kingdom, are helping to overcome this problem by using the PerkinElmer® AutoIMAGE™* Fourier Transform-Infrared (FT-IR) microscope to examine fine grained material from primitive meteorites found on Earth. These meteorites were formed in the same environment as the molecular dust clouds so they contain many of the same chemical species as molecular dust, which makes them a valuable source of reference data. When Morlok matches the IR spectra found in a meteorite to one found in outer space, he can then analyze the meteorite sample with an electron microscope to perform a mineralogical characterization and in this way identify the materials that presumably played a role in the earth's formation.

* The AutoIMAGE system is superceded by the Spotlight 200 system. The Spotlight 200 delivers even higher performance than the AutoIMAGE predecessor.

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Raw materials for star formation

Earth was originally made from gases condensed to solids such as nitrogen, oxygen and ammonia and rocks from the calcium, silicon, magnesium and iron groups. Life depends on the complex chemistry of organic compounds built around carbon atoms. The stars were the sites where these materials were created. Stars manufacture heavy elements in the course of nuclear fusion. At the end of their lives, massive stars explode and less massive stars slowly shed gas enriched with these heavy elements that in turn coalesces to form other stars. In each cycle of star birth and destruction, the proportion of heavy elements increases as the byproducts of nuclear burning in the center of stars is added to the mix. Over billions of years, complex chemistry and biology have evolved from their simple beginnings in the first stars and galaxies. Now astronomers are traveling back through time to witness crucial steps in our origin.

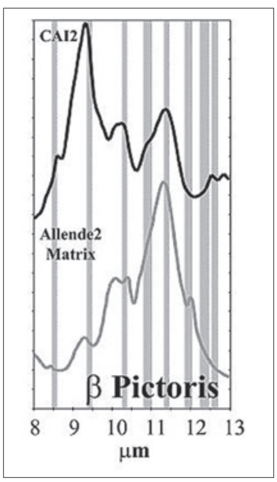

Figure 1. Two mid-Infrared spectra of powdered materials from a primitive meteorite are shown. A CAI is a complex of minerals formed very early in our solar system, the fine grained matrix is material produced at a later stage. The horizontal bars are band position found in the astronomical spectra of the dust in the circumstellar disk around Beta Pictoris (Figure 3, Knacke et al, 1993).

The molecular clouds generated by stars at the end of their lives provide the raw material for the formation of new stars and planetary systems such as our own. When the temperature in the circumstellar disk becomes low enough, a dust condenses out of the gas. A rich range of chemical reactions occurs, including creation and depletion of heavy elements onto dust grains and into ices. Interstellar molecular clouds are also the principal formation sites of organic matter such as CH_4, CH_3OH, and H_2CO. The composition of the dust provides valuable information on the conditions when the dust was formed and helps determine subsequent steps involved in star formation. Comprehensive understanding of heavy element creation and depletion and the important role of dusty material in star and planetary system formation is needed to understand the chemical conditions from which life on our planet arose. These investigations can be pursued with spectroscopic studies of molecular clouds and dust that exists throughout the universe. Several telescopes have been launched into space that permit mid- to far-Infrared spectroscopy to be used to determine the composition, temperature, density and velocity of the molecular clouds.

A major problem needs to be overcome. The Infrared spectra generated by platforms such as the Infrared Space Observatory (ISO) in the late 1990s and the Spitzer Space Infrared Telescope Facility which is operating now, are often unknown. One of the most important discoveries of the ISO was that crystalline silicates exist outside our own solar system. This is significant because the relatively sharp features of crystalline silicates are sensitive to compositional changes, in contrast to broad and smooth amorphous silicate features. To increase our understanding of the crystallization process, we need to positively identify the composition of the wide range of crystalline silica spectrum that has already been identified in molecular clouds.

"Just like human fingerprints uniquely identify their owner, Infrared spectroscopy provides a spectral fingerprint that uniquely identifies a chemical compound," Morlok said. "The challenge facing scientists is that, just like it is impossible to match a fingerprint to a person unless you have previously taken that person's fingerprint, it's impossible to determine the composition of a compound based on its spectra until you have analyzed an identical sample on earth. But the chemistry in molecular clouds is, to a large degree, unknown on the earth; and it will be a long time before we are able to travel to distant stars and galaxies to analyze the many compounds that we have already generated Infrared spectra from."

Meteorites provide potential for identification

Several types of crystalline dust grains have been extracted from meteorites that were formed in the molecular gas environment, including silicates, nanodiamonds, silicon carbide, graphite, silicon nitride, corundum, hibonite, and spinel. Laboratory investigation of the meteorite samples with instruments such as electron microscopes, ion microprobes, atomic force microscopes, synchrotron microprobes, and laser probe mass spectrometers will provide an extraordinary opportunity to examine interstellar grains at the highest possible level of detail. The comparison of these materials with primitive meteorites and collected interplanetary dust samples will provide the basis for examining the pre-solar solids that were involved in solar system formation. These data will provide fundamental insight into the materials, processes, and environments that existed during the origin and early evolution of the solar system over a wide range of distance from its center.

Morlok is working to establish a database of Infrared spectra of crystalline silicates found in primitive meteorites. These spectra can be compared to spectra from astronomical observations of dust in molecular clouds, discs around young solar systems, and interstellar wind ejected from supernovas. Morlok is one of the first to go beyond the use of terrestrial minerals and standards for use in fingerprinting remote sensing spectra.

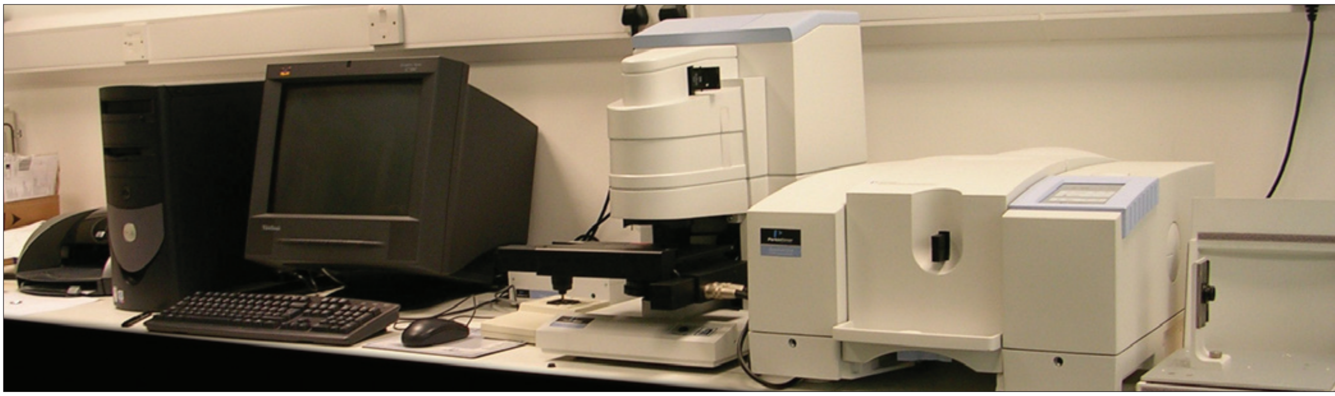

Figure 2. The AutoIMAGE microscopy and Spectrum One systems in the laboratory at the Natural History Museum of London.

The first challenge that he faces is separating the common and well-known materials that constitute the vast majority of most meteorites from the tiny organic and inorganic grains that might shed light on the formation of the solar system. He uses mechanical methods and an optical microscope to separate out the grains. Grains that are in the milligram size range can be analyzed directly with a conventional Infrared spectrometer. But many grains have dimensions in the tens of microns, about one-fifth to one-tenth the width of a human hair, and their weight is measured in nanograms. Once he has separated the grain, he then grinds the material and places it in a diamond compression cell that flattens soft samples for measurement by transmission. The sample is compressed to optimum transmission thickness, which also has the effect of making the sample area larger.

Move to Infrared microscopy

"Analyzing nanogram samples on a conventional FT-IR spectrometer would be very time-consuming and require a great deal of skill, particularly to centralize the sample in the disk," Morlok said. "Several years back, we switched to Infrared microscopy, which greatly reduces the amount of sample preparation. Coupling an FT-IR instrument to an IR microscope provides identical information to that of traditional IR spectroscopy but allows the IR light and therefore the measurement area, to be much smaller, enabling the measurement of microscopic samples or very small areas within samples. Fourier transform processing yields clear spectra in very little time."

Morlok's supervisor, Professor Monica Grady, recognized the need for an FT-IR microscope. So Morlok compared several different options and selected the Spectrum™ One FT-IR* spectrometer and AutoIMAGE microscope from PerkinElmer, Shelton, Connecticut. "One reason that I selected both the AutoIMAGE and Spectrum One was that they provide a coherent system that makes it possible to seamlessly move

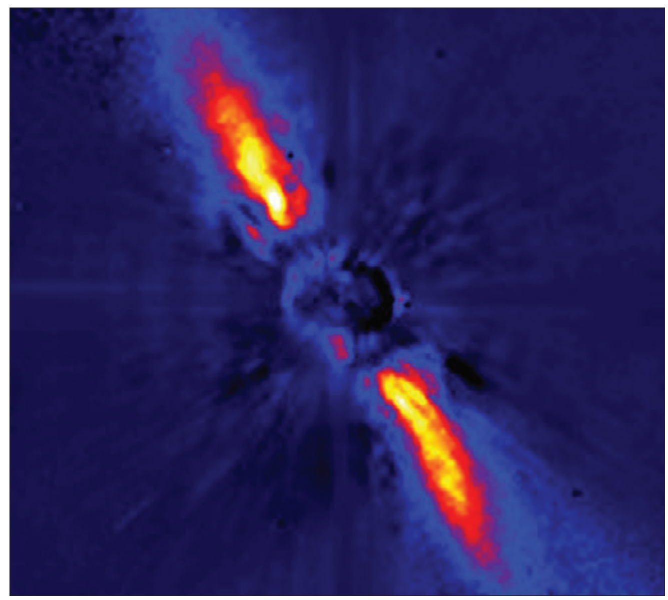

Figure 3. An Infrared image of the circumstellar disk around the young star Beta Pictoris (edge on view, (C) European Southern Observatory).

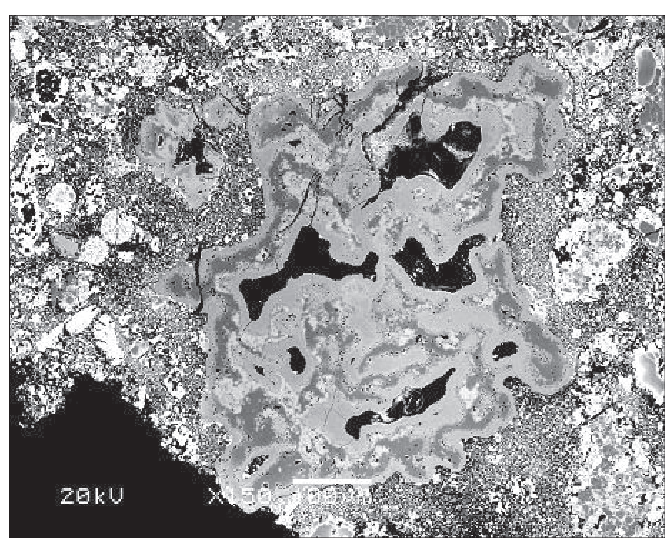

Figure 4. A scanning electron microscope image of a CAI (irregular shaped thing in the center) and matrix material (fine grained material around it).

* Spectrum One is superceded by the PerkinElmer Frontier IR sytem. This system delivers even higher performance than the Spectrum One FT-IR.

from analyzing larger samples on the workbench to analyzing smaller samples on the microscope using similar methods and producing comparable spectra," Morlok said. "While several competitive instruments have minimum sample sizes of 25 µm by 25 µm, the AutoIMAGE's superior sensitivity and optical performance generates clear spectra from samples as small as 10 µm by 10 µm." The AutoIMAGE is also unique is its class by offering all three modes of IR sampling as standard: 1) transmission mode for films, laminates, fibers and crystals 2) reflectance mode for surfaces and thin films on reflective surfaces and 3) micro ATR for highly absorbing samples such as black rubber, filled polymers and paper.

Morlok has already identified a number of crystalline silica spectra from his meteorite samples that were seen in the cosmos but never in terrestrial samples. Despite the progress he has made, the road ahead is long. Tiny changes in chemical composition, morphology, and temperature and pressure at time of formation can generate spectral differences so astrophysicists are continually adding to the list of unidentified spectra. Yet Morlok believes that the efficient methods he has developed will make it possible to rapidly build his database of known spectra, contributing to our knowledge of how the earth was formed.

For more information about PerkinElmer and the AutoIMAGE microscope, please visit the company's website at www.perkinelmer.com/irmicroimaging

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