Comets Appear to Be Rosetta Stones

After their closest look yet, astronomers are increasingly hopeful that comets are largely unaltered since the formation of the solar system and perhaps even earlier

CONVENTIONAL thinking among astronomers has been that comets are the most pristine remnants of the dust and gas that formed the solar system 4.6 billion years ago. Whatever story they have to tell about the stuff that made the solar system, it can be read more or less directly. Reading that story in detail is one of the major goals of the barrage of scientific studies that greeted Comet Halley. Researchers are only just beginning their work, but already there are renewed assurances that the stuff from which the solar system formed has been preserved more or less intact.

One reason for optimism is that the composition of Halley is as predicted. The ices making up the bulk of Halley are composed of the gases expected to condense onto dust particles in the extreme cold of the fringes of the pre-solar nebula or interstellar space. Armand Delsemme of the University of Toledo published his best estimate of the composition of comets before the spacecraft encounters with Halley in March. On the basis of recent Earth-based analyses, he predicted that the gases released by the icy nucleus would be 83% water, about 6% carbon monoxide, 4% carbon dioxide, and even smaller amounts of a variety of trace components. The proportions are those expected if the components of the sun condensed at 30 Kelvin without any major subsequent losses due to heating. An otherwise unexplained dearth of carbon in comet gases relative to the composition of the sun might be made up by an average of 20% of organic matter in comet dust, he predicted.

Delsemme was right. As became evident at the recent meeting* in Heidelberg on Comet Halley, mass spectrometric analyses made by the Halley spacecraft confirmed his principle expectations and those of others, including the secreting of much of the expected carbon in organic-rich dust particles. As Johannes Geiss of the University of Bern pointed out in his overview talk, Halley appears to have held onto two to ten times more of the lighter elements carbon, oxygen, and nitrogen relative to rock-forming silicon than did the meteorites. At least in terms of these more volatile elements, Halley seems to have a composition more typical of the solar system's starting materials than do the rocks formed far closer to the sun at much higher temperatures.

Rocky dust, on the other hand, seems to have had the same composition wherever it was incorporated into solar system bodies. Rock-forming elements were found in Halley dust in the same proportions as in chondritic meteorites. Chondrites, some parts of which have obviously solidified from large globules of melted rock, have the most primitive composition of any meteorite, that is, their composition most resembles that of the sun. VEGA team members working on results from the PUMA dust experiment reported in Heidelberg that the abundances of rock-forming elements in 23 dust particles fell within a factor of 2 of their abundances in type C1 chondrites.

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The isotopic composition of Halley also tends to support the idea that comets are representative samples of early solar system material. The stable isotope ratios of carbon, nitrogen, and sulfur, among others, fall in ranges expected for solar system material. Comets do not seem to be alien invaders from outside the solar system. However, the current isotopic ranges are still rather large, due in part to the complexities of mass spectra made under spacecraft conditions that cannot be reproduced in the laboratory. Nothing on the earth can accelerate micrometer-size dust particles to speeds of 70 kilometers per second, the impact speed of comet dust vaporized on the inlets of spacecraft instruments.

Some of the other newly determined isotopic compositions are providing useful constraints. Peter Eberhardt of the University of Bern and Giotto's neutral gas mass spectrometer team reported a deuterium-hydrogen ratio of between 0.0006 and 0.0048, which is compatible with meteorite and terrestrial values.

Halley not only appears to have a composition thought to be similar to that of the solar system's starting material, but also its dust comes in forms too delicate to have suffered much alteration since adhering to one another 4.6 billion years ago to form comets. According to Halley spacecraft analyses, the smaller the comet dust particles are, the more numerous they are, down the size spectrum past the 1-micrometer size once thought typical to particles 0.01 micrometer in size. Some micrometer-size particles actually fall apart after leaving the vicinity of the nucleus to produce such ultrasmall particles. Some small grains are solely rock dust, in some cases a single mineral grain, and others contain only carbon, hydrogen, oxygen, and nitrogen, pure organic matter called CHON particles.

It seems unlikely that such small particles, as much as a million times less massive than cigarette smoke particles, would survive even the mildest heating without disappearing by evaporation or fusion. In fact, Halley's particles seem to resemble the interstellar dust that formed by condensation in space. It was such interstellar dust, presumably coated with ices, that was gathered along with non-condensable gases to form the sun and the solar system. Whether some or all of the dust spewing from Halley survived since the formation of interstellar dust long before the solar system existed remains uncertain. The possibility that the Halley spacecraft analyzed unaltered stuff from between the stars seemed to appeal to many researchers.

A number of speakers at the Heidelberg meeting noted that their results supported the interstellar dust model of Mayo Greenberg of the University of Leiden and, by unspoken inference, his contention that comets may contain recognizable interstellar dust. Greenberg himself did not carry things that far, commenting only that "the coincidences between interstellar dust and cometary dust make it worthwhile to pursue this further." Geiss concurred. "All results point

*Twentieth ESLAB Symposium on the Exploration of Halley's Comet, 27–31 October in Heidelberg, West Germany. Abstracts are contained in European Space Agency (Paris) publications Sp-250. The proceedings will be published at the end of this year.

toward [Halley containing] pristine material of the solar system present during its formation," he said. "What we know of interstellar dust, but that's very little, is compatible with the Halley results [as well]," he added. Whether interstellar dust simply agglomerated on the frigid fringes of the solar nebula to form Halley, or interstellar dust vaporized in the heat of the solar nebula and then recondensed remains to be seen.

Geiss emphasized that a productive application of the Halley analyses would be to use them to identify which of those particles now being collected in the earth's stratosphere are comet dust. Some of these relatively large interplanetary dust particles have been proposed as possible comet dust. But Robert Walker of Washington University in St. Louis points out that to produce more than the present circumstantial evidence linking the two, extensive analyses must be performed on stratospheric dust at the size scale of Halley dust. All the Halley particles whose impact-vaporized remains were analyzed by spacecraft instruments do not equal one 10-micrometer stratospheric dust particle, he notes. The analytical tools to duplicate the Halley analyses in the laboratory are only now becoming available.

Even before researchers could see that Halley is made of enticingly primitive material, it was obvious that there must be a great deal more cometary material in the solar system than once thought. Until the spacecraft got close enough to pierce Halley's shroud of dust and gas, most astronomers presumed that unseen comet nuclei were bright or at least not too dark and therefore relatively small, typically a few kilometers across. But instead of being bright and 6 kilometers in diameter, as recently predicted, Halley's nucleus is black and about 16 kilometers long and 8 kilometers wide.

On the basis of the old assumptions, Paul Weissman of the Jet Propulsion Laboratory had calculated that the Oort cloud, the tenuous halo of comets circling the sun far beyond Pluto, contained 2 Earth masses of cometary material. Incorporating the blackness of nuclei as well as other recent developments into his calculations, Weissman now estimates that the Oort cloud contains 25 Earth masses of comets. That makes it easier for comets to have supplied Earth's reservoirs of water and other volatile gases through bombardment early in the history of the solar system. It also means that comet impacts created a larger proportion of the impact craters on Earth, a possible cause of biological extinctions. And, notes Weissman, comets may constitute a significant fraction of interstellar material, which was assumed to be almost all gas and microscopic dust. ■ Richard A. Kerr

Synchrotron X-rays Probe Coronary Arteries

Although not yet up to clinical quality, images of coronary arteries in three patients at Stanford encourage hopes for a safe and inexpensive diagnostic technique for heart disease

The first images of coronary arteries in human patients taken by means of a new technique that requires the intense radiation from a synchrotron light source have been reported by researchers at Stanford. Although the images are not yet of clinical quality, the technique is considerably less invasive and potentially less expensive than coronary angiography, the x-ray method now in widespread use for detecting trouble spots in the system of arteries that supply blood to the heart.

It is conceivable that geographically scattered regional centers housing compact synchrotron x-ray sources could someday provide coronary artery imaging services for those diagnosed as having heart disease. Long-term serial studies for establishing the natural history of coronary atherosclerosis and its response to treatment, as well as widespread screening of those at risk for this disease but not yet evidencing any symptoms are other possibilities.

Coronary angiography requires that a catheter be inserted into a patient's peripheral artery (in the thigh, for example), after which it is pushed through the arterial system toward the heart. The tip of the catheter is moved to the point in the aorta where either the left or right coronary artery has its origin, according to which is to be imaged, and a concentrated dye containing x-ray absorbing iodine is injected into the artery. The x-ray image therefore shows where blood is flowing normally in the coronary arteries and where the flow is reduced or blocked altogether because of atherosclerosis.

Although coronary angiography generates images of high quality, it poses some risk to the patient. In a presentation in October to the annual users' meeting of the Stanford Synchrotron Radiation Laboratory (SSRL), where the experiments were done, Edward Rubenstein of the Stanford University School of Medicine* noted that complications occur in about 1% of patients. These include heart attacks and strokes when the insertion of the catheter dislodges from the walls of arteries atherosclerotic deposits that then travel to the coronary arteries or to the brain. Fatalities occur about 0.1% of the time.

In addition to the risk, coronary angiography is expensive and requires a 2-night stay in a hospital. The average cost is about $3500. Nonetheless, because coronary angiography is essential before heart surgery, almost one million procedures are done each year in the United States, so that providing this service is a multibillion dollar enterprise. Although heart disease remains the leading cause of death in the United States, coronary angiography is plainly an unsuitable technique for screening large numbers of nominally healthy people in an effort to find those who are developing life-threatening conditions.

Conventional coronary angiography requires injection of the concentrated dye because of the low sensitivity of x-ray imaging systems to the dye. Synchrotron radiation has three features that combined with electronic x-ray detectors and computers make possible an attractive alternative to angiography. The first is that synchrotron light comes in a smooth, continuous spectrum; the second is that the light is very intense; and the third is that the beam is naturally highly collimated.

Because the beam is collimated, researchers can use a crystal monochromator to select by Bragg diffraction any wavelength of interest from the broad spectrum, and the high intensity guarantees enough x-ray photons at the selected wavelength to be useful. By recording image intensities with an electronic detector at two wavelengths, one just above and one just below an x-ray absorption edge for iodine (or another chemical element) in a dye and subtracting the logarithms of the intensities from one another on a computer, it is possible to eliminate nearly all contributions to an image except those due to the dye.

*In addition to Rubenstein, the researchers are Robert Hofstadter, Herbert Zeman, and John Otis of Stanford University; Albert Thompson of the Lawrence Berkeley Laboratory; George Brown of the Stanford Synchrotron Radiation Laboratory; John Giacomini, Helen Gordon, Robert Kernoff, and Donald Harrison of the Stanford Medical School; and William Thomlinson of the National Synchrotron Light Source.