Research in Progress

Comet Composition

NEXT MARCH 13th will be the culmination of years of effort on the part of Peter Eberhardt, visiting associate in geology and planetary science. He'll be in the European Space Agency's operations center at Darmstadt, West Germany, monitoring data returned by the Giotto spacecraft as it encounters Comet Halley. Aboard Giotto is an instrument Eberhardt helped design — the Neutral Gas Mass Spectrometer (NMS) — that will return precise information on the composition of the gases swirling around Halley. Because these gases are thought to represent nearly pristine remnants of the early solar system, data from the NMS are likely to solve important questions about the state of the solar system before the formation of the earth.

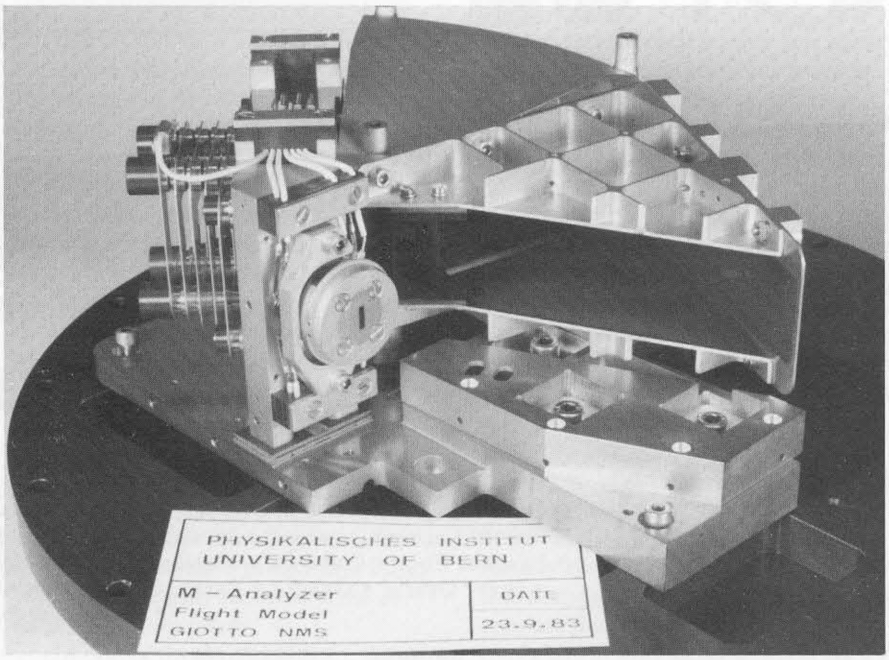
Traveling towards Halley at 69 kilometers per second (154,000 miles per hour), Giotto carries nine other instruments aside from the NMS. There are two other mass spectrometers — one for ions and the other for dust — as well as ion, dust, electron, and energetic-particle analyzers; a camera; a magnetometer; and an optical photometer. Giotto has been aimed to plunge directly into the comet, missing Halley's solid nucleus by only 500 kilometers. If things go according to plan, Giotto will pass through the comet's shock front, its contact surface, and its coma before dust particles destroy the spacecraft or knock its antenna out of alignment with the earth.

Until this happens, the NMS will be sending a steady stream of data back to Eberhardt and his colleagues at Darmstadt. "We will look at the data online as they come in and, if necessary, we'll make changes in the operation modes of the instrument," says Eberhardt. "We'll get quick-look data in real time, but to really reduce the data will take considerable time — probably several years."

Mass spectrometers work by first ionizing a stream of gas and then subjecting this stream of ions to a strong magnetic field. The magnetic field deflects ions of low mass more sharply than ions of higher mass, so ions of different masses will strike different locations on a suitably placed detector. The position of a signal on such a detector indicates the atomic mass of the ionized gas, and the intensity of the signal indicates the gas's relative abundance.

The NMS aboard Giotto consists of several separate modules, each designed and built by a different research team. A group at the University of Bern, where Eberhardt is professor of physics, designed the mass spectrometer itself — the "M-analyzer" — and performed instrument calibrations and environmental testing. A group at the Max Planck Institute in Heidelberg built the E-analyzer, which will measure the temperatures and streaming velocities of the cometary gas. Scientists at the Laboratoire de Geophysique Externe near Paris were responsible for the detectors and ground support electronics, and researchers at the University of Texas, Dallas, built the NMS's electronics and wrote the onboard software.

The design groups had to solve a number of important problems before the idea of sending a mass spectrometer to the comet could become a reality. For one thing, the instrument would have to be capable of detecting anywhere from one single gas molecule to one-billion of them. When the NMS is 100,000 kilometers from the comet, the gas densities will be on the order of 10,000 molecules per cubic centimeter; says Eberhardt, "this is a pretty good vacuum for most people." To measure such a rarefied atmosphere, the signals will be preamplified



A Swiss research group built the M-analyzer, the heart of Giotto's Neutral Gas Mass Spectrometer. Gas molecules enter a small slit, at left center in this photograph, and are separated according to mass by the wedge-shaped magnet at the rear.

by a specially designed micro-channel plate, which contains, in effect, 256 tiny photomultiplier tubes, whose gain can be changed by adjusting the high voltage.

Another problem in measuring such low gas densities is that a substantial fraction of the gas molecules in the vicinity of the NMS will be molecules that have evaporated from the spacecraft itself. To discriminate against these non-cometary molecules, the designers took advantage of the fact that the comet's gas will be traveling at a high velocity relative to the spacecraft. By setting up a potential barrier (an area of high positive voltage) just past the instrument's ionization region, only molecules with high thermal energy will be able to enter.

"What we want to get from the NMS," says Eberhardt, "is the chemical composition of the neutral gas evaporating from the cometary nucleus. How much water, methane, CO, N_2, and so on is there? We will measure also the isotopic composition of the light elements — for instance the $^{18}O:^{16}O$ ratio, deuterium abundance, and ^{13}C. We'd like to study what happens to the gas when it expands into space, its interaction with sunlight, the spatial distribution of changes with distance. At present we don't really know what the composition of the volatiles is. We have some information from spectroscopy, but we may actually be missing a few major components because they cannot be seen with spectroscopy."

Some of these measurements have important implications for theories about the early solar system. A good example of this is deuterium abundance. The earth is enriched in deuterium, a non-radioactive isotope of hydrogen. Deuterium is twice as heavy as hydrogen, and its relatively high abundance on earth is thought to be due to low-temperature fractionation — before the accretion of the earth a disproportionate amount of the lighter hydrogen in the inner solar system had been lost. The outer planets have much lower deuterium abundances, and this is thought to reflect the solar system's initial conditions. Most scientists believe that Halley's comet formed in the outer solar system so its deuterium abundance should be similar to that of the outer planets.

If all goes according to plan, data on this question and others will start streaming down to Darmstadt on March 13, 1986, three hours and 45 minutes before Giotto's closest approach. As this day nears, Eberhardt is spending part of a sabbatical at Caltech, "I've been fairly busy with the Giotto project in the last two years, busier than I intended to be." Eberhardt will likely remember these months at Caltech as the calm before the storm, a storm that will bring a blizzard of data to bear on some of the most fundamental questions in the solar system. □ — *RF* their prices. This can lead to a situation in which ultimately no buyers take advantage of the price lists and prices remain uniformly high. "You can see why this can be in equilibrium if you think about it," says Grether. If everybody charges high prices, there's no real point in paying money to shop. If nobody pays money to shop, there's no point in charging lower prices because your business won't go up.

To Shop or Not to Shop

THINK ABOUT THE LAST TIME you bought a major durable good — a television, a washing machine, or a refrigerator, for example. Did you just buy the first one you saw in your price range? Or did you compare prices and qualities, going from store to store say, or reading newspaper ads or *Consumer Reports*? If you fall into the latter group, you're known in economic lingo as a "shopper," and the more people there are like you in a given market, the lower prices will be overall.

At least that's the conclusion that David Grether and Louis Wilde, both professors of economics, and Alan Schwartz, professor of law and social science, have arrived at by applying a novel combination of economic theory and experiment. These studies began several years ago when Wilde and Schwartz were developing mathematical representations of markets in which the consumer has only imperfect and costly sources of information. The researchers discovered that their models were difficult to test against competing ones, so — together with Grether — they began a series of experiments designed to test market behavior in the laboratory. They study how buyers interact with sellers in the marketplace by varying such factors as a market's structure, its proportion of shoppers to non-shoppers, and the amount of information available to buyers and sellers.

Their laboratory is a simple classroom and their subjects are paid volunteers who take the part of buyers and sellers. Although no actual goods are bought or sold in these experiments, to properly motivate the subjects, real money must change hands. Sellers purchase "goods" from the researchers and sell them for whatever the market will bear. At the end of the experiment, buyers resell the "goods" they have purchased to the researchers at a predetermined price. All participants get to keep any profits they make, which can amount to as much as $7 per experimental hour.

"We aren't just asking how well these subjects can calculate something that we could in principle simulate on a computer," notes Wilde. "We give them discretion over how to behave and we provide incentives for them to behave in an economically rational fashion. We give them a reason why, if they're a buyer, they should like a lower price, and a reason why, if they're a seller, they should like a higher price. But we don't dictate what prices to transact at or how to behave. Whether they make money or not is their own problem."

In an initial series of experiments Grether, Schwartz, and Wilde have confirmed several theoretical models that predict the behavior of markets having varying proportions of shoppers. If none of the buyers are shoppers, for example, prices stabilize at a very high level. If all of the buyers are shoppers, sellers will charge very low prices, just above their costs. And if the market contains some shoppers and some non-shoppers, at equilibrium the sellers will be selling their goods at an array of prices. This shows that even non-shoppers benefit when a market contains a sizable proportion of shoppers. One of the goals of the research is to determine just what this proportion has to be.

More recently, the researchers have turned to studies in which an "information broker" is interposed between buyers and sellers. Such a situation mimics some of the computer-organized markets or electronic shopping services that have begun to spring up with the advent of television cable systems and personal computers. In this kind of service a prospective buyer can, for a fee, gain access to a list of sellers and their prices.

In one of these experiments, the information broker offers buyers the option of purchasing a list containing a limited sampling of the sellers and their prices. This can lead to a situation in which ultimately no buyers take advantage of the price lists and prices remain uniformly high.

But if shoppers can choose to purchase a complete listing of all the sellers and their prices rather than just a sampling, the outcome changes completely. "Generally in this setup," says Grether, "all transactions take place at one of two prices — either a low price — a competitive price — or a high price, with no prices in between. If you're a seller and you're not at the low price, you don't get any business from shoppers at all. So once you come off the bottom, there's no point in coming off a little bit." Only non-shoppers, of course, buy at the high price.

"It turns out," says Wilde, "that small changes in the way people gather information or in the way information is disseminated can have very significant implications on the predicted nature of the market outcome. There are issues about how sellers would get listed on such a marketing service: Do firms demand to be on it? Do they pay a fee to be on it? Does the information service itself go out and sample firms? Is it always the same firms or is it a random sample? The difference, for example, between the information service going out and randomly sampling 10 firms every week versus having a stable of 10 firms it always monitors would lead to completely different outcomes."

Since minor changes in a market's structure can lead to drastic differences in its functioning, this work may have significant implications for government policymakers. "That's the whole nature of the research," says Wilde. "To try to understand how these different features influence the outcome, to ask, 'What would be the socially responsible way to regulate these services, and do we even need to regulate them?'" So one of the most important results of these studies may be to provide lawmakers with data on which to base their regulatory decisions. □ — *RF*