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What Have We Learned About Halley's Comet?

Now that the recent outbreak of "Halley fever'' has died down and the media have returned to reporting the escapades of Hollywood's stars, what should we tell our students about the past year of comet investigation? What did we learn from the eight spacecraft that explored the comet from nearby and far away and from the hundreds of ground-based instruments that were pointed at the icy visitor whose passage occasioned so much interest?

While much of the data analysis and interpretation is still underway at universities and observatories around the world, we wanted to begin sharing some of the highlights of the discoveries with *Universe in the Classroom* readers.

The Core of the Comet

Until the Russian *VEGA* and the European *Giotto* spacecraft flew by Halley's core, people had never really seen the heart of a comet! By the time a comet like Halley becomes visible to us, the little "dirty snow ball'' that is its core is completely veiled by the much larger *coma* — the cloud of evaporated ice and loosened dust produced by the action of sunlight on the core. As a comet nears the Sun, its coma can stretch some 100,000 kilometers or more across (10,000 times larger than the iceberg that produced it.) Thus, it is fair to say that the most eagerly awaited result from the space missions was our first glimpse of what the comet looked like at its heart.

That glimpse produced a great surprise — the core is not round, but instead has an irregular shape rather like a huge unshelled peanut. Photographs taken by the European *Giotto* probe — which passed closer than any of the other probes — showed that the comet's nucleus was about 15 kilometers long and 8 kilometers wide. (See the accompanying box for a way to compare these numbers to the other parts of the comet and the rest of the solar system.)

The pictures returned by *Giotto* (and the Russian *VEGA* probes) also reveal the comet nucleus to be much darker than we expected. Most of the surface is so black that it reflects only about 4% of the light that hits it — less than black velvet reflects! Astronomers hypothesize that this dark material is dust and complex molecules left over when the comet's more volatile ices evaporated as it came close to the Sun. The photographs show bright geysers of gas and dust spewing out from the dark surface.

In fact, *Giotto*'s cameras almost missed the comet's nucleus as a result of its unexpected darkness. Since Earthbound controllers couldn't communicate with the distant spacecraft quickly enough to make changes during the crucial moments of the encounter, the sequence of photographic instructions had been coded into onboard computers. Since astronomers expected the comet's nucleus to be made of bright reflective ices, they programmed the cameras to center the photos on the brightest object they "saw''. That brightest object turned out to be a bright geyser of escaping material — but, luckily, the nucleus can still be seen off to the side of each frame!

Giotto's photographs, which are being computer processed to bring out evely possible detail, also show some craters on the nucleus and several features that look like Earth mesas. The vents from which the material for the coma and tail was escaping when the comet was near the Sun made up only 10% or so of its surface. The vents seem to be active only when exposed to the Sun, shutting off very quickly as the rotation of the comet brings them to its "night'' side.

A Scale Model for Halley's Comet

Suppose we could shrink the nucleus of Halley's Comet down to the size of a real peanut (in the shell, about an inch and a half (4 cm) long). On that scale, what would be the size of other parts of the comet and our solar system at the time of *Giotto*'s close encounter with the comet in March?

The comet's coma (the cloud of evaporated gas and loosened dust) would be about 270 meters wide, a little bigger than a metropolitan sports stadium. The largest extent of the comet's hydrogen cloud (see main article) at this scale would be more than 33 km across, larger than most towns.

On the same scale, last March 14th the Sun was a 5-km (2-mile) wide ball of gas, located about 500 km from the comet, while the Earth was a rocky ball about 35 meters wide also about 500 km from the comet but in a different direction.

The *Giotto* spacecraft came within 600 km of the comet's nucleus, surviving the great gas and dust storms of the inner coma. On our scale model, the spacecraft would be a tiny speck, flying within one and a half meters (five feet) of the peanut.

(More advanced students can, of course, be asked to make such scale model calculations on their own. That way, they will be much more likely to remember the results.)

Comet Halley's dark icy nucleus (center) and bright "jets'' of gas and dust as photographed by "Giotto''. (Photo courtesy of ESA.)

The Full Extent of the Comet

The *Pioneer Venus* spacecraft, orbiting our sunward neighbor planet, turned its ultraviolet-sensitive instruments toward the comet and was able to record the full extent of its hydrogen cloud for the first time. This hydrogen cloud forms when the Sun's energy hits the water vapor molecules freed from the comet's icy core and dissociates them into hydrogen and a special combination of the remaining oxygen and hydrogen atoms called a hydroxyl radical. These lighter components spread out farther and, in a sense, mark the boundaries of the comet's coma.

What *Pioneer* found was that the hydrogen cloud surrounding Comet Halley last spring grew as large as 20 million kilometers (12.5 million miles), some 15 times larger than the Sun. During this time, Halley's cloud was one of the largest structures in our solar system.

Halley's Rotation Period

While astronomers had strongly suspected that the comet rotates and had even made an estimate of its rotation rate from photographs and drawings made during its last pass in 1910, this pass allowed us to pin down the rotation rate (in a sense, the length of Halley's "day''). The comet rotates every 52 hours and the "day'' side — the one facing the Sun — is significantly more active than the night side.

Composition and Temperature

Instruments aboard the spacecraft were able to make careful measurements of the composition of the comet's *sublimated* gases. (Sublimation is the process in which a solid turns directly into gas, which is what we would expect the comet's heated ices to do under the extremely low pressure conditions of space.) As astronomers had predicted, most of the gas coming off the comet is water vapor — about 80% to be exact. About 3 to 4% is carbon dioxide, and a substantial amount of the remainder is carbon monoxide, a simple combination of one carbon and one oxygen atom.

The observations of Halley's nucleus revealed fascinating variations of temperature within the comet's icy core. The spacecraft measured the outer layers of the nucleus to be about 330 kelvin (57 degrees above freezing) on the sunlit side in March. Since the temperature required for sublimating ice under the conditions near the comet is about 215 kelvin, this means the excess heat at the surface can be conducted down into lower (cooler) layers where there is still ice. The sublimated gas then comes out through the vents that open to the surface, explaining the bright jets the *Giotto* cameras showed us.

In a brilliant and subtle experiment, a group of astronomers making observations with the Kuiper Airborne Observatory (a converted jet aircraft with a 91-cm telescope on board) were able to estimate the temperature of the solid ice within the comet's core from the characteristics of the different types of ice molecules that eventually emerged. They found that the ice inside the comet nucleus is as cold as 35 kelvin — just 35 degrees above absolute zero!

The Comet is Not Forever

As students quickly realize when they study comets, the very activity that makes these tiny icebergs visible to us across the solar system means that the comet will get smaller each time it passes by the Sun. One of the primary goals of the Halley observations was to measure the rate at which the famous cornet is losing its mass. Preliminary estimates indicate that about 1/1OOOth of the comet's mass is lost per apparition. Roughly, a layer 10 meters deep is lost from the comet each time it comes into the inner solar system. Clearly, Halley has a good number of 76-year orbits left before it stops making news.

On the other hand, the unshelled-peanut look the nucleus currently sports has led a number of astronomers to remind us that other comets have in the past split into two a more parts as they swung by the heat of the Sun. Could it be that during some distant future pass of Comet Halley humankind (if we can survive our own follies that long) will be treated to a pair of Halley's Comets in our skies?
