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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

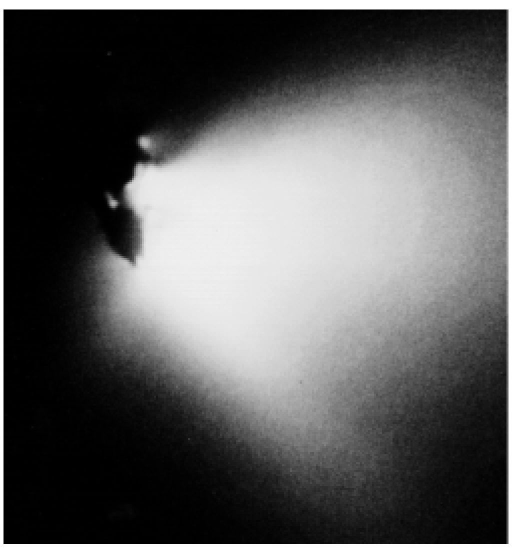
Suppose we could shrink the nucleus of Halley's Comet down to the size of a real peanut (in the shell, about an inch and a half (4 cm) long). On that scale, what would be the size of other parts of the comet and our solar system at the time of *Giotto*'s close encounter with the comet in March?

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?

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The Search for Planets Around Other Stars

As we live out our lives securely attached to the Earth, breathing its air, and using its water, it becomes all too easy to take planets for granted. After all, our solar system has nine of them, enough so students grumble each year about having to remember them all.

Yet the surprising fact is, we do not know for certain whether there are planets around other stars. We strongly suspect they are there; many of our best-established theories indicate that the creation of planets is a likely accompaniment to the birth of many kinds of stars. But as of today, we simply do not have any firm evidence that planets outside our own solar system exist.

Planets Are Hard To Find

The problem, as always in astronomy, is one of distance and brightness. While stars shine under their own power, planets simply reflect the light of their parent star. Furthermore, planets are generally much smaller than stars and the surface or atmosphere on which starlight can reflect is thus very limited. If a planet like the Earth orbited the nearest star to us, the light it would reflect would be too dim to be picked up with even the largest telescope on Earth!

A few years ago there was a flurry of excitement as some astronomers found wobbles in the motions of several nearby stars, suggesting the presence of planets. To understand how these observations were performed, imagine a star with just one good sized planet around it. When the planet is on one side of its star, its gravity pulls the star ever so slightly to that side. Then as the planet moves in its orbit to the other side, it tugs the star just a bit to that side.

From far away, we cannot see our hypothetical planet at all — it is just too dim. What we do see is the much brighter parent star. If we could make extremely precise measurements of its motion as the years pass, we might be able to detect a tiny wiggle in its movement, as the planet pulls it first to one side and then to the other. While this technique is fine in theory, in practice it turns out to be depressingly difficult.

Let us suppose that the star in our example is our nearest neighbor star Proxima Centauri and the planet in question is the largest planet in our own solar system, Jupiter, moving around Proxima Centauri in the same orbit in which Jupiter circles our Sun. How large a wiggle would we observe in the motion of Proxima Centauri over the course of decades? The answer turns out to be about 0.032 seconds of arc, or the size of a U.S. quarter as seen from 95 miles away!

Some years ago astronomers at one observatory, after decades of observations, reported the discovery of such wiggles in the motion of a few nearby stars. However, neither the discoverers nor other astronomers have been able to duplicate these findings. It may be that small changes in the telescope over the decades simulated wiggles. In any case, everyone agrees that we will need to watch the suspect stars carefully for another decade or so to pin down whether or not wiggles exist and if they are caused by planets (rather than, for example, small dark stars in orbit around the visible stars).

In the meantime, what can we say about the likelihood of planets existing around the hundreds of billions of stars in our Galaxy? Recently, a number of fascinating new clues in the planet puzzle have been found by astronomers working in a variety of research fields.

Discovering a Brown Dwarf

In 1984, astronomers Donald McCarthy and Ron Probst reported the discovery of an object which is halfway between a planet and a star — a stillborn star, if you will — too small to engage in the nuclear fireworks that sustain a star. The term astronomers use for such an object is *brown dwarf* and, although they had been predicted to exist by a number of astronomers, this would be the very first of this cosmic species to be found

The brown dwarf orbits one of the very faintest and coolest stars we know, called van Biesbroeck 8 (after the astronomer who found it) Located at about 21 light years away, in the direction of the constellation Ophiuchus, VB8 (as we affectionately and more pronounceably call it) was found in 1983 by astronomers at the U.S. Naval Observatory to show just a bit of a wobble.

Reasoning that a cool faint system like this might be more easily observed with infrared (heat rays) than visible light, McCarthy and Probst used the 4-meter telescope on Kitt Peak in Arizona to take many short exposures of the star in infrared light. They then combined these exposures using special computer processing techniques to bring out very faint details that might otherwise elude detection. Using 10,000 exposures taken over several nights (interrupted by the bane of astronomers — night rain), they found the star had a close companion about 16 times fainter in infrared light than the star.

Further observations indicated that the object had about the diameter of Jupiter and was located about the same distance from its star as Jupiter is from the Sun. But its mass and temperature make this object unusual. It weights in at an estimated 40 times the mass of Jupiter and has a surface temperature of 1400 degrees Kelvin (about 2000 degrees Fahrenheit) — much too massive and hot for a planet, yet too cool and underweight to be a star — and thus likely to be our first example of a brown dwarf.

However, we should add one important note of caution. As this issue was going to press, two teams of astronomers who had been trying to duplicate the observations of the dark companion around VB8 reported that they had been unsuccessful. Even the discoverers have urged caution about accepting their observations until more evidence is obtained.

For now, the object is known as VB 8B, hardly the most ear-catching of names. While school children have already written to Dr. McCarthy with suggestions for names ("Starbit'', "Farheat'', "Mongo'' and the like), the feeling now is that we must wait until we are certain that this object exists, what it is and how many more like it there are out there before a name is assigned that may set a precedent.

Should the observation be confirmed, its significance for the question we are considering will be enormous.

Hot news from *IRAS*

In 1983, a sophisticated orbiting telescope called the *Infra Red Astronomical Satellite* (or *IRAS* for short) spent 11 months observing the sky with "infrared eyes''. Among its many discoveries was that 12 nearby stars were surrounded by shells or disks of dark particles, not bright in visible light but glowing with the heat rays their warmth produced. At least some of these could be raw material from which planets could be forming or may already have formed.

Unfortunately, a vast swarm of smaller particles can scatter radiation much more efficiently than a single large body like a planet. Thus if there are planets in any of these systems we are unlikely to be able to see them with present technology. Still, the disk around one of these stars, called *Beta Pictoris*, has been photographed by two astronomers using specialized electronic detectors and a large telescope atop a Chilean mountain. The disk around Beta Pictoris stretches out some 10 times the size of Pluto's orbit.

Recently, astronomers have concentrated their attention an a star in the constellation of Taurus called *HL Tau*. Surrounding this youngish star, measurements made with radio waves have revealed enough gas and dust to make ten Jupiters, orbiting in a disk about three times the size of our own planetary system. While we cannot say that this system is producing planets, it certainly appears that the raw material for making them is there.

Thus we continue to be tantalized by hints that the process that led to planets in our cosmic "neck of the woods'' may have occurred and be occurring elsewhere. Should planets be discovered someday orbiting other stars, it will be difficult to resist speculating whether some of these planets may be capable of supporting life as our Earth does. This topic, so loved by science fiction writers and Hollywood, will be the subject of a future issue of *The Universe in the Classroom*.

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Activity Corner

Astropuzzle

by Dennis Schatz, Pacific Science Center

In the set of letters below (which you may wish to copy onto a separate sheet far distribution to the class) are hidden a significant number of astronomy related words. A word can be made by starting with any letter anywhere in the puzzle and then moving to adjacent letters. You can move up, down, left, right, ar diagonally and you may change your direction of motion as many times as you wish while you are forming a word.

Example: Start with the M in the middle of the 5th line; go up and diagonally to the A, down to the R and right to the S — you have MARS.

O	P	L	S	C	M	T	M
S	M	A	U	R	E	V	I
T	I	B	T	N	Y	T	Q
D	E	P	E	O	A	U	P
I	P	R	O	M	R	S	L
J	U	N	I	D	A	T	A

Suggested Scoring:

25 words = Observatory Director
21 words = Astrophysics Professor
15 words = Assistant Professor
11 words = Graduate Student
9 words = Night Assistant

Editor's Note: The record for the number of words found in the puzzle by an individual is 64. Of course, the number of acceptable words depends on how liberally you interpret "astronomical term.'' Some classes have used the puzzle as a challenging library assignment.