The Halley Flotilla

FIVE SPACECRAFT FROM THREE NATIONS GREET THE MOST FAMOUS COMET AROUND

Robert Cattrysse

Three years after World War II not much attention was given to Halley's Comet. 38 years earlier the Comet was feared by the people of Earth that the discovered poisonous cyanogen in the gases making up its tail would kill us all when we swept through it on that May day in 1910. That never happened and in 1948 the Comet's outward journey which carried it over 4.5 billion kilometres from the Sun suddenly stopped. The Comet was at aphelion or farthest approach from the Sun, beyond the orbit of Neptune. Its motion then reversed itself and the Comet tumbled back to the Sun. Its inward trip to the Sun carried it past the orbits of Neptune, Uranus, Saturn, Jupiter, Mars, Earth, and Venus. As the Comet neared the Sun its coma was formed around the nucleus and then came its long, wispy tail growing ever so larger. The Comet then zipped by the Sun after perihelion or closest approach to the Sun on February 9, 1986 and began its trip once again to the cold, dark depths of space but not before it was welcomed by Earth in a different manner since it was first recorded in 240 B.C.

In early March 1986 as the Comet headed towards the Earth five spacecraft from three nations performed the first detailed study of a comet and its environment. The fleet of spaceprobes came from the Soviet Union, Japan and the European Space Agency (ESA), a consortium of eleven European nations. The international Halley flotilla began their journey from Earth on December 15, 1984 with the launch of the Russian Vega 1. Six days later, on December 21, Russia's Vega 2, which is identical to Vega 1, was launched into space. Japan launched its Sakigake spacecraft on January 8, 1985 (Japanese time), January 7 local time. ESA launched their Giotto probe on July 2, 1985. The final Halley spacecraft, the Japanese Suisei, was launched on August 19, 1985 (Japanese time), August 18 local time. Sakigake and Suisei are Japan's first two interplanetary spacecraft, both launched by the Japanese Institute of Space and Astronautical Science (ISAS).

Where did the names come from? Vega is an acronym formed from the Russian name of the mission--Venera-Gallei--a contraction of the Russian words Venus (Venera) and Halley (Gallei). The Japanese probes Sakigake means pioneer and Suisei means comet. Sakigake was originally called MS-T5 and Suisei was originally called Planet-A. The European Giotto spacecraft was named for the Florentine painter Giotto di Bondone, who must have seen the Comet in 1301 and then painted it in 1304 as the star of Bethlehem in his fresco "The Adoration of the Magi." Giotto avoided using a traditional, stylized star and instead, painted a comet modelled after the one he himself had observed only a few years earlier. His version of Comet Halley is not the geometrical comet of the Bayeux Tapestry (the Comet's 1066 appearance when William of Normandy defeated England's King Harold II at the Battle of Hastings in 1066), but a naturalistic portrait, a careful description of a comet's appearance. For this reason, some have called Giotto's painting the first scientific description of a comet.

The Vegas began their job early, way before the Halley encounters. On June 11 and 15, 1985, they stopped by Venus and dropped two balloon probes into the atmosphere of the planet and two landers to the planet's surface. Each balloon radioed back pressure, temperature and wind data for 46 hours while hovering 54 kilometres above the planet's surface. The balloons stopped transmitting when their 18 flashlight-size batteries were exhausted.

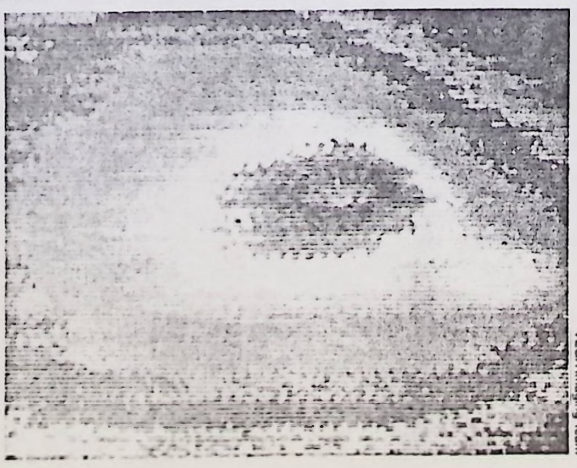
An optical device detected cloud particles in the Venusian atmosphere and a small photo-electric instrument counted lightning discharges.

Both the Vega 1 and Vega 2 dropped helium-filled balloons on Venus's night side, where they encountered a pressure of about one-half Earth's atmosphere (as measured at sea level). They recorded temperatures ranging from 20 to 70 degrees Celsius in being carried by the wind from the night side to the day side of Venus at about 250 kilometres per hour. From earlier probes it is known that the wind speed at the cloud tops (an altitude of 70 kilometres) is even greater, about 360 kilometres per hour. It is believed the balloons moved in an eddy, the Vega 1 balloon at the peak and Vega 2 at the trough. This may be why the temperature recorded by Vega 1 seven degrees north of the equator was consistently 6.5 degrees Celsius higher than that recorded by Vega 2 at seven degrees south. Further evidence for eddies on Venus is the turbulence encountered by the balloons. Then came the Vega 1 Halley's Comet encounter.

100 foreign scientists gathered at Moscow's Institute of Space Research to observe the eagerly awaited rendezvous of Vega 1 with Halley's Comet. On March 6 at 2:20 a.m. EST Vega 1 passed 8889 km of Halley's nucleus and as images of the legendary Comet flashed on television screens at the institute, Cornell University astronomer Carl Sagan joined other foreign scientists in applause, while Soviet scientists and technicians hugged and kissed one another. Vega 1 had become the first man-made object to visit Comet Halley. "This is the first time we've gone to the Comet," said Sagan.

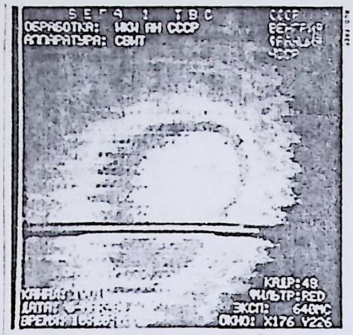
As applause could be heard from scientists Carl Sagan said on a special edition of the ABC NEWS program Nightline, "The Vega 1 spacecraft has successfully penetrated through the coma of the Comet." Sagan was sitting beside Assistant Director of the mission Karoly Szego. The mission was indeed a great cooperation between the U.S. and U.S.S.R.

Vega 1's camerawork was a triumph of technology. While whipping by Halley's at a speed around 280 000 kilometres an hour (relative to the Comet), the spacecraft's TV cameras shot some 500 pictures in about three hours. Transmitted across 175 million km of space, each picture took nine minutes to arrive in Moscow, where it was coloured by computer to emphasize differences in brightness. The first images showed only the coma, the great cloud of gas and dust surrounding the nucleus, as a fuzzy, violet-fringed, blue-green ball with a yellow centre. But in images that Vega 1 shot



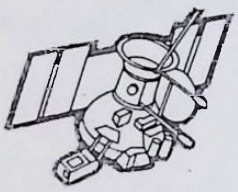
What appears to be two objects in this Vega 1 image is actually the result of computer processing that divides the scene into discrete regions of increasing brightness. The nucleus is approximately centered, with a possible bright jet at lower right.

when only 9000 km from Halley's, a dark red
area with rather dis- tinct boundaries ap-
peared near the centre of the image, and sci-
entists crowded close to the television
screens. "How big is that area?" asked one.
"Three or four kilome- tres," said a Soviet
scientist. "Evident- ly, it is the nucleus."
His announcement drew a burst of applause.
Though some scientists speculated that another
dark area near the centre might be a sec-
ond nucleus, others suspected that it was
a high-velocity jet of dust shooting from a
solitary nucleus.



Television image of Halley's core, recorded by Soviets' *Vega 1*

To astronomer Fred Whipple, 79, another American who journeyed to Moscow, the image was further confirmation of his 1950 "dirty snowball" theory, which holds that a comet has a small, solid core of ice and dust. "The fact that the Comet's image came out with a bright centre shows we were seeing the nucleus," he said. "If that were simply dust, we wouldn't see the irregularities we saw."



VEGA 1

The CCD camera electronics were colder than nominal and they suffered some sort of interference that produced a wavy pattern in the images. Both effects can be corrected by computer processing. The 3 channel spectrometer gave degraded performance, and a plasma wave experiment failed 30 000 km before encounter.

Early evaluation of data from Vega 1 showed that the craft encountered less dust than expected as it approached the Comet. But Physicist John Simpson of the University of Chicago, who designed the only American instrument--a dust detector--aboard Vega, noted that as the spacecraft departed, it passed through a "huge spike of dust" with particles about the size of those in cigarette smoke. Simpson and other scientists interpreted the spike as a burst of dust and gas erupting from the surface of the nucleus. Other Vega instruments seemed to show that the icy cometary surface was being evaporated by solar radiation at a rate two or three times as fast as scientists had predicted.

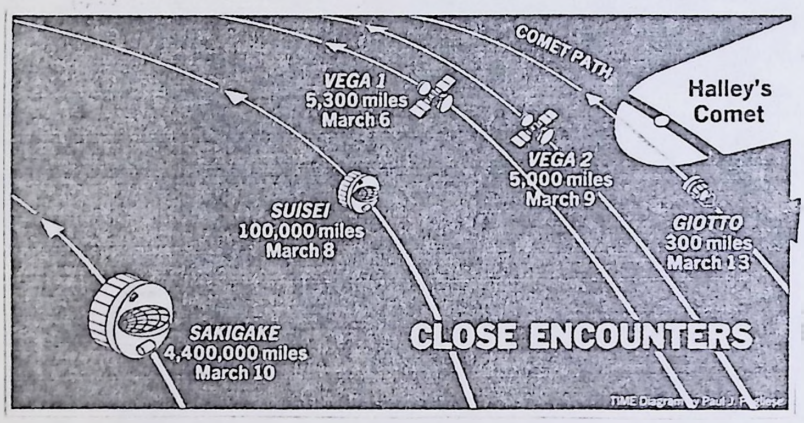
The dust impact experiments recorded a 40-times increase in dust flux over ambient in less than 4 seconds near close approach and dropping off more slowly afterward. Water at 2.7 microns (one micron is equal to one millionth of a metre or one thousandth of a millimetre) and carbon dioxide at 4.26 microns were detected by the infrared spectrometer/mapper, as well as a double emissive feature on the nucleus. The infrared spectrometer also reported evidence of hydrocarbon molecules among its early findings. It also indicated temperatures within the Comet's dusty coma to be about 57°C (300K ± 20K). This was higher than anticipated by some researchers, suggesting at least the possibility that the excess might be due to heat retained by the enveloping dust, which Space Research Institute Director and Vega mission Director Roald Sagdeev termed a "dust cocoon."

Particle impacts in the dust jet reduced the power output from Vega 1's solar panels by 45 percent. Fortunately, the panels were there merely to charge the craft's batteries, which saved the day--by design--when the going got heavy.

Vega 1 completed its mission successfully and it also served as the advance for the other four spacecraft.

With Vega 1's job complete it was time to turn the eyes to Japan's

Suisei spacecraft. Two days after Vega 1's encounter, on March 8 at 8:01 a.m. EST, Suisei flew by Halley's Comet at a distance of 155 000 km. Images from Suisei's ultraviolet camera, relayed to the Institute of Space and Astronomical Science in Tokyo, showed that Halley's huge hydrogen coma (radius: 9.7 million kilometres) appeared to brighten and darken in a cycle of 53 hours, which seemed to confirm other observations that the nucleus rotates about once every two days. The Japanese were surprised when Suisei recorded hits by two cometary dust particles, each more than a millimetre in diameter. The two dust particles caused a temporary, partial signal loss near the close approach. Said Project Manager Tomizo Itoh: "It was quite a discovery that dust particles that size were traveling that far away from the nucleus."



The ultraviolet camera aboard Suisei also confirmed a phenomenon known as bow shock, which arises from interactions between the gases of a comet and the solar wind (a stream of particles emanating from the Sun). Astronomers have theorized that just as the bow of a moving ship creates a wave, so the passage of a comet through the solar wind should create a sharply defined magnetic boundary. The Japanese craft as well as others in the armada found that Halley's bow-shock region is, as expected, about 966 000 kilometres from the nucleus.

Somewhere around the orbit of Mars, volatile materials start to evaporate off the Comet's surface. Water (H_2O) is the main volatile, and as it is blown off the surface, sunlight breaks the molecules up into their component parts. The hydrogen forms a gigantic cloud, millions of kilometres in diameter, around the head of the Comet. Suisei carried an imaging system that watched in extreme ultraviolet light, viewing the emissions in the hydrogen Lyman-alpha spectral line. Hydrogen Lyman-alpha images of the coma have been obtained, and there are plans to continue.

On the following day the Soviet Vega 2 passed Halley's Comet at a distance of 8030 km at 2:21 a.m. EST on March 9. Vega 2 went closer to the nucleus than Vega 1 and dust impacts reduced the solar panel power output by 80%. Yet officials gathered at the Space Research Institute were puzzled. Although Vega 2 had gone closer, data from dust detectors aboard the two craft seemed to indicate that Vega 1 had flown through one of the Comet's jets, while Vega 2 had not. Early looks at the data, in fact, suggested that Vega 2 had been struck by three to four times fewer dust particles than its predecessor. Aided by photos from the two craft, scientists concluded that by the time Vega 2 went by, the Comet's nucleus had rotated so that the jet was no longer crossing the flyby trajectory. Yet there was more damage to Vega 2's solar panels, perhaps underscoring that a few well-placed impacts can sometimes do more damage than a whole dust storm. After all, the Pioneer and Voyager spacecraft that went to Jupiter, Saturn and Uranus passed through the asteroid belt,

planetary rings and radiation belts with little or no damage. The spacecraft sent back 700 pictures and confirmed that the nucleus was solid.

The CCD camera on Vega 2 suffered a "stuck" bit which made flat fielding difficult. The microprocessor used for pointing the camera platform failed one day before encounter, so the star-tracker backup had to be used. All but two near encounter images were over-exposed. The result was very good signal-to-signal noise on the many weak jets that were starting to form at the time. The magnetometer lost two of its direction channels, and the infrared spectrometer/mapper cryogenic system failed to cool the detector, apparently because of a leak in the cooling system. The dust flux was much more symmetrical than for Vega 1, indicating no jets, but larger mass particles were detected.

On March 10 the Japanese Sakigake spacecraft passed 7.1 million kilometres from the Comet. It detected sporadic "plasma waves" that were described by Hiroshi Ohya of Tohoku University as being "akin to the electric waves of lightning." The waves, which originated in a region between 402 325 km and 1 005 813 km from the Comet's core, apparently result from the interaction of solar wind with the fluctuating outer edge of the cometary coma. Time of encounter: 11:30 pm.

Both Japanese spacecraft did not make very close encounters with the Comet, a good move for a nation with its first interplanetary missions. The long, straight ion tails streaming out behind the Comet's head are formed primarily by the solar wind blowing across the Comet's nucleus. Solar flares cause "gusts" in this wind, propagating shock fronts through interplanetary space. These fronts may cause turbulence in both the ion tail and coma. Therefore, it is important to measure the solar wind simultaneously with several spacecraft in the vicinity of the Comet.

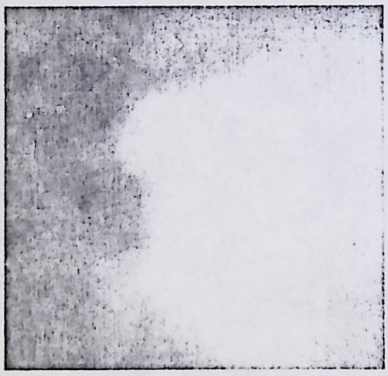
Suisei investigated the behaviour of particles within the solar wind. Sakigake studied the structure of the solar wind, measuring plasma waves, solar-wind particles and magnetic fields. Scientists coordinated the experiments on these two spacecraft that flew between the Sun and the Comet, ensuring that solar-wind conditions affecting the Comet can be more completely understood.

Then came Giotto. On March 13 at 7:02 p.m. EST the European Space Agency's Giotto spacecraft made its closest approach to Halley's Comet, a mere 605 kilometres. At the control centre in Darmstadt, West Germany the tension became palpable as the Comet and Giotto raced toward each other at a closing speed of 249 000 kilometres per hour. Images of the Comet, relayed to the centre at intervals of four seconds, loomed larger and larger on television screens, finally yielding by far the best look yet at an elongated shape near Halley's heart. It was the Comet's nucleus. Giotto Investigator Wolfgang Schmidt, giving a play-by-play description of the images, could not contain his excitement. "It's obvious that there is structure on this nucleus," he exclaimed. "Mountains, hills, craters--incredible detail!" Suddenly the image froze and then, only two seconds before the spacecraft's closest approach to the Comet, the screens went blank.

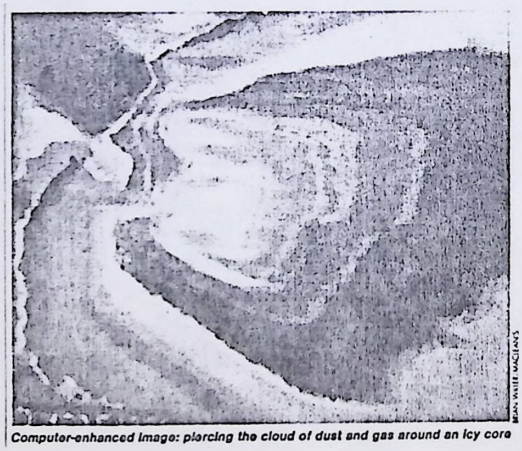
The Giotto encounter was indeed the spectacular that scientists had hoped for. Limited by battery capacity, it was not turned on until 4 hours 19 minutes before its closest approach, and 71 minutes later it took the first of about 2000 pictures of the huge coma. The real prizes, however, were its pictures of the nucleus, taken from as close as 1530 km.

Information from the other spacecraft helped ESA in their flyby. The close targeting was especially possible through the use of Intercosmos Vega images for the final navigation. One of the worst fears of the international Giotto team was that the spacecraft would most likely be destroyed by the dust particles traveling at tremendous speeds. It was a great risk to get the first closeup pictures of a comet.

In the last seconds before the encounter, Giotto ran into what one scientist described as a "wall of dust the size of grains of sand." The spacecraft's protective dust shields were peppered with particles at a rate of 100 impacts a second, a bombardment that swung its antenna out of alignment with a tracking station in Australia. Scientists at first thought Giotto's mission was over, as the television images became distorted and then blanked out and all their data from the ten on-board instruments disappeared. Some 34 minutes later, its data was picked up again, as the spacecraft's "nutation dampers" succeeded in stabilizing what had only been an abruptly induced wobble and restored continuous communication with Earth. All but two experiments were working. The camera no longer worked and a star mapper used for attitude control stopped functioning after encounter. There was no solar power panel loss (they were on the side of the spacecraft and protected from direct impact from dust), but there were some thermal control problems which may be related to thermal blanket erosion.



Halley's nucleus, upper left, viewed by the approaching *Giotto*
Obvious structure: "mountains, hills, craters—incredible detail!"



Computer-enhanced image: piercing the cloud of dust and gas around an icy core

The camera transmitted over 2000 images before the final one at a range of about 1000 km, (50 metres resolution), but the last few frames were affected by a progressively more dirty mirror. Said Dr. Carl Sagan live from Darmstadt, West Germany on ABC NEWS World News Tonight, the only U.S. network from the three to have live coverage of both the Vega 1 and Giotto encounters, shortly after the closest approach: "It seems to have survived Ted (Ted Koppel substituting for Peter Jennings in Washington). 14 seconds (later reports said 2 seconds) before encounter, just the moment that the pictures starting jumping around on us, the spacecraft seems to have been hit by one or more large particles which tilted and spun it up so that the antenna no longer was pointing back to the Earth. Since then, signals have been acquired from the spacecraft, although it is still drifting, and when that happened there were cheers that went up in the control room. The spacecraft, by in large, seems to have survived the encounter."

The potato-shaped nucleus appeared to measure about 15 km long by 8 km wide, making it not only more irregular than expected but also considerably larger than the roughly 3- to 6- km estimates of the past. From Earth-based observations, the earlier estimates had been built on an assumed reflectivity for the nucleus--if it was shinier, a given measured brightness would mean it was smaller. But as Giotto camera-team leader Horst Keller of the Max Planck Institute in West Germany described it, "There's no question that the true colour of the nucleus is black, absolutely black, blacker than coal, almost like velvet." This did not mean that cometary nuclei no longer seemed to be "dirty snowballs," Whipple's theory (Whipple was also present for the encounter at the control centre in Darmstadt, West Germany). Far more likely is that near the Sun, the "lighter," outer areas of exposed ice are vaporized more readily by heat than are those covered by dust--leaving a more uniform blackness.

But though they still seem to be made of ice/snow, "ball" may be a less appropriate term than just "icy conglomerate," composed perhaps of various fragments that may even come apart occasionally and then regroup as nondescript lumps. Or, as Paul Weisman of the Jet Propulsion Laboratory (JPL) in Pasadena, California, suggested even before the spacecraft flybys, loosely bound "rubble piles."

Keller said that the surface is "velvet black and very irregular, with an indentation in the middle, like a peanut or a potato." On one side of the nucleus were what appeared to resemble nozzles, spewing out one minor and two major jets of gas and dust. Keller was puzzled by the blackness of the nucleus, which suggested that there actually could be little or no ice on its surface. Whipple's explanation was that the Comet's surface might be covered by densely packed, extremely small particles embedded in an icy mantle.

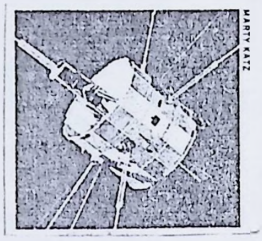
Besides taking pictures, the $380-million 2.7-metre long cylindrical spacecraft sent back to Earth 145-million kilometres away a wealth of other data. Instruments measured the Comet's composition (reporting carbon, oxygen, hydroxyl and other constituents) and other characteristics, and sent the researchers back to their home institutions with a treasure trove of data like none they had had before. It had easily been, as one scientist said, "the greatest week cometary science has ever had or is likely to have for some time."

According to U.S. National Aeronautics and Space Administration (NASA) official Burt Edelson, the mission was "an absolute triumph of international co-operation"; Giotto was guided in the final hours of its eight-month flight by information supplied by the Soviet Vegas. On January 24 the Giotto probe ran into difficulties. Engineers could not receive engineering data. They had lost communications with Giotto. NASA used one of its antennae in Australia to pick the signal up again. (Giotto had always been in contact with Earth. Its camera was turned on 4 hours 19 minutes before closest approach because of limited battery capacity, although Giotto was also powered by solar cells, as well as the other four spaceprobes.)

All together five spacecraft visited Halley's Comet on its 28th recorded return. Where was the spacecraft from the United States, a world leader in the space program? The reason, simply, was because of the lack of money. On December 5, 1985 Carl Sagan said on ABC NEWS Nightline with Ted Koppel: "The basic reason given by both the Carter and Reagan Administrations is that it would cost too much to have a U.S. probe of Halley's Comet. How much would it cost? It

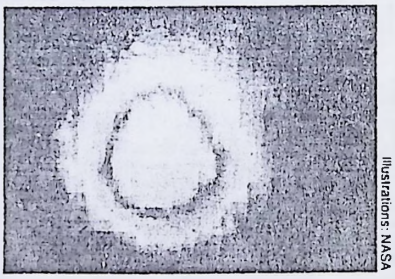
would cost just about the same as a B-1 Bomber of which we are committed to purchase a hundred. Ninety-nine would compromise national security. I think the comparison shows something, there are many other examples of it, of how our priorities are in a warped state."

Vega 1 was the first spacecraft to encounter Comet Halley but not the first to encounter a comet. On September 11, 1985 the U.S. International Cometary Explorer (ICE) flew through the tail of Comet Giacobini-Zinner (G-Z). ICE had not been designed to go to a comet, so it lacked cameras and many other instruments of the sort carried by the Halley fleet. It did, however, enable scientists to compare another comet in some ways with Halley. On October 31, 1985 ICE passed Halley's Comet at a distance less than 150 million kilometres. ICE passed even closer on March 28, 1986, within 30 million km. The spacecraft provided data on the solar wind upstream from Halley's Comet; at the same time, Earth-based telescopes observed the effect of the solar wind on the Comet's tail. These measurements will help us determine the cause-and-effect relationship of the solar wind and cometary tails. ICE was launched on August 12, 1978, originally known as the International Sun-Earth Explorer 3 (ISEE-3), monitored the solar wind near the Earth-Sun Lagrangian L_1 point. The probe was rerouted to G-Z in the summer of 1982.



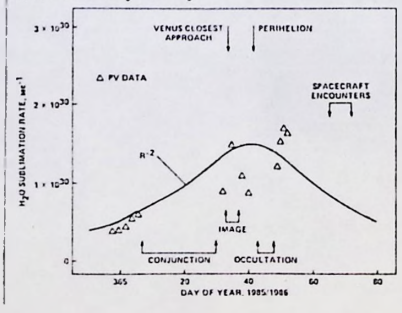
A model of ICE

The U.S. had other ways to study the celestial celebrity. Included were SPARTAN and Astro-1. The Shuttle Challenger carried the Shuttle Pointed Autonomous Research Tool for Astronomy (SPARTAN) when it exploded 73 seconds into launch on January 28, 1986. The carrier box was to be deployed by the Canadarm and retrieved one day later. The reusable box would have been the first satellite to observe the Comet. Observations, most of them in sunlight, were to take place as Halley raced toward the Sun. On March 6 the Shuttle Columbia was to carry Astro-1, a collection of instruments designed for astronomical observations from low Earth orbit. The impressive payload of three ultraviolet (UV) telescopes and two wide-field cameras were to study the Comet for the available period during each orbit, free of interference from Earth's atmosphere. It was cancelled.



Illustrations: NASA

The orbiting Pioneer Venus (PV) spacecraft in January got the best view of Comet Halley's closest approach to the sun. Water-vapor brightness measurements yielded the image above (ring shapes are result of processing) and showed (triangles below) that the amount of water vapor coming from the comet's nucleus was varying by factors of two from day to day.



The Pioneer 12 spacecraft was launched by the U.S. on May 20, 1978 and it has been orbiting Venus since December 1978. The probe took time out from looking at Venus and turned its eye to Comet Halley. The Venus-orbiting Pioneer spacecraft, which in January had experienced the closest view of the Comet's closest approach to the Sun (perihelion: February 9, 87.9 million km), had revealed that the amount of water vapour coming off of the nucleus did not vary smoothly with the changing heat input. Instead, it would double or drop by half from one day to the next, with hints that the variations could be even more rapid. "It turns on so suddenly," said Jeffrey Cuzzi of the NASA Ames Research Center at

Moffett Field, California. "Like popcorn." Commented principal investigator Ian Stewart of the University of Colorado in Boulder before the Giotto encounter (who is now refining his data to see how big the changes were from hour to hour), "There's a tremendous amount riding on that Giotto camera."



SOLAR MAX

The Solar Maximum Mission (SMM), nicknamed Solar Max, was launched by the U.S. on February 14, 1980. In November 1980 the satellite went dead so in April 1984 the five man crew of the Space Shuttle Challenger retrieved, repaired, and redeployed it on the 11th Shuttle flight (STS 41-C). The satellite observed Halley's Comet from Earth orbit.



PIONEER 12

The International Halley Watch (IHW) was organized in 1981 to coordinate ground-based study of Comet Halley and to assist Halley space missions where possible. The U.S. is the major country behind the IHW. Its goals were to (1) advocate studies of the Comet by any scientifically valid means, (2) coordinate the activities of ground-based observers to maximize the scientific return of all investigations, (3) set useful standards for observations, (4) place the spacecraft missions in the context of overall cometary behaviour, and (5) archive all the properly documented data collected during the Halley apparition. The scope of the Halley Watch was broadened to include a Giacobini-Zinner Watch in support of the International Cometary Explorer.

In the past Halley's Comet appeared suddenly in the night sky. Many times have the people of Earth thought of, not only Comet Halley, but other comets as well, would bring destruction to the Earth and its civilizations. Today we know they are just "dirty snowballs" drifting endlessly in space, sometimes breaking up and being engulfed by the Sun. When the Comet returns to Earth's vicinity in 2061 we will study it even closer. We will do what the United States of America had planned for this apparition. We will land a spacecraft or two on the surface and study the Comet as it nears the Sun and leaves once again. There will not only be tours, cruises and jet flights so you can get a better view of the Comet but there will also be space cruises. People traveling in spacecrafts will get spectacular views of Comet Halley. Thanks to the international Halley flotilla and the other ways the world studied this apparition of Halley's Comet, we now know more about comets, the origin of the universe and who we are.

THE NEXT MISSION:
COMET RENDEZVOUS

