Comet Kohoutek—

containing water vapor at low pressure. These electrons have sufficient energy to knock other electrons from the orbitals of the water molecules, thus creating a plasma of H_2O^+ and electrons. The plasma spectrum is photographed and then analysed to pick out those elements due to the newly formed ion. Though most of the emission lines are from H_2O^+ (there are thousands of them), some are due to other sources such as hydrogen and must be eliminated to arrive at a true picture of the ion's spectrum."

The events that led up to the identification of H_2O^+ in the comet provide a good example of the detective-like manner in which evidence is pieced together in science to form a larger picture. The first clue arrived on Dr. Herzberg's desk from an Italian Observatory in the middle of December, 1973; it was a report of observations taken on 29 October, 1973, while the comet was still far out from the sun and relatively cool.

"Soon after Kohoutek became visible I received a photograph of its spectrum from Dr. P. Benvenuti and Dr. K. Wurm of the Asiago Observatory in which they indicated four prominent emission features that they could not identify," says Dr. Herzberg. "Since Dr. Lew's spectral analysis of H_2O^+ had not been available to them (it had not yet been published), we checked their unknown lines against his spectrum, and sure enough, the H_2O^+ ion had emission lines at these places."

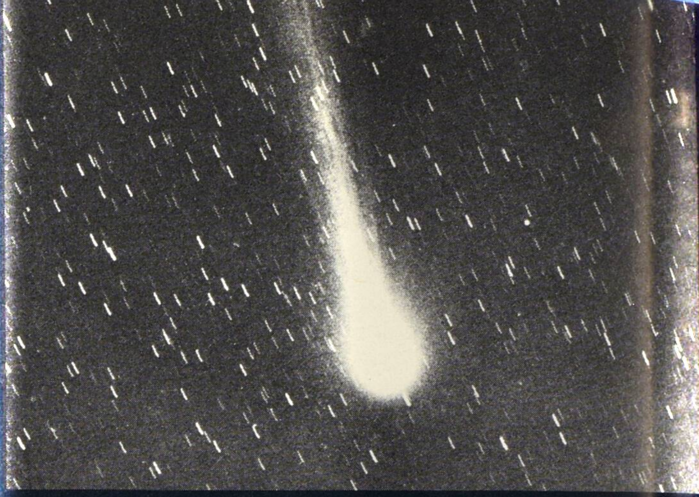
The lines in the Italian photograph were of very low resolution, with an accuracy good to about one Angstrom at best, and there were only four matchings out of thousands of possible lines in the H_2O^+ emission spectrum. This agreement would not therefore have meant much unless there was something more in the data than just the coincidence of wavelengths. It turned out that these emission lines were precisely the ones that would be expected from the ion if the temperature of the comet was low. They corresponded to emissions involving excitation from the lowest rotational level of the ion's electronic ground state and were the most probable lines to be found in the cold environment of the distant comet.

Shortly thereafter the NRC scientists learned of a bulletin from the International Astronomical Union (IAU) containing observations of the comet by Dr. G.H. Herbig of the Lick Observatory in California. Dr. Herbig's spectrogram, taken on November 8, 1973, contained two of the unidentified lines from the Italian photograph, as well as a third line, also unknown. All three of his lines were in good agreement with values listed in Dr. Lew's table for H_2O^+, and the resolution was greater than in the Italian spectra by a factor of seven.

"We felt sufficiently certain of the evidence by this time that we wrote a paper entitled, "The Tentative Identification of H_2O^+ in the Tail of Comet Kohoutek"," says Dr. Herzberg, "and sent a copy to NASA which in turn alerted the central office of the IAU. The IAU routinely sends out telegrams all over the world informing astronomers of recent developments in the field. About a month later, in the middle of January, 1974, we received a telephone call that provided virtually conclusive evidence for the presence of the ion in the comet tail."

The call came from two Israeli astronomers, Dr. P. Wehinger and Dr. S. Wyckhoff at the Wise Observatory in Israel's Negev desert, who had photographed the comet tail with the aid of a device called an image intensifier on the night of January 10, 1974. A recent development for use in night viewing, this instrument was ideally suited to photography in the red-yellow spectral region where the H_2O^+ lines occur and photographic plates are "slow" (do not pick up details well). The resultant spectrogram contained a number of lines which the astronomers could not identify. Since they were aware of the IAU Herzberg-Lew bulletin, they made some rough measurements and telephoned Canada.

"They read off some line wavelengths over the telephone," says Dr. Herzberg, "and we compared them with the H_2O^+ table. Though their data corresponded to emission lines in our spectrum, their figures were not precise and we had to wait for more accurate measurements to be made."



The Comet Kohoutek, photographed on 29 November 1973, at Cerro Tololo, Chile, when it was still 90 million miles from the sun. During the 20-minute exposure, the comet moved against the background stars, and because the telescope was set to track it, the stars show up as short streaks. The molecular ion H_2O^+ was identified in the comet tail, seen extending across the photograph from the head region. • La comète de Kohoutek photographiée le 29 novembre 1973, à Cerro Tololo, au Chili, alors qu'elle était encore à 90 millions de miles du Soleil. Au cours d'une exposition de 20 minutes, la comète s'est déplacée sur un fond étoilé et, comme le télescope la suivait, les étoiles apparaissent sous forme de tirets lumineux. L'ion moléculaire H_2O^+ a été identifié dans la queue de la comète dont on peut voir également la tête et la chevelure.

Two weeks later the spectrogram arrived from the Negev observatory, followed somewhat later still by precision measurements of the lines.

"We knew simply by looking at the spectrum that it was H_2O^+," says Dr. Lew. "It showed the same progression of bands, or groupings of emission lines, as the H_2O^+ ion; there was the same alternation between two distinct types of band structures. The arrival of the precise measurements merely added to the weight of evidence indicating the presence of the ion. About the same time Dr. Herbig also sent along even more precise data, putting the identification beyond a shadow of a doubt. A paper summarizing these results, entitled 'The Identification of H_2O^+ in the Tail of the Comet Kohoutek (1973f)' and authored by the two Israelis, Dr. Herbig and ourselves, has been published in the Astrophysical Journal Letters."

The identification of H_2O^+ in the tail of Comet Kohoutek provides the first conclusive evidence for the presence of water in comets, and lends support to F.L. Whipple's description of these cosmic wanderers as "dirty snowballs" rather than say, "gravel banks", as suggested by another cosmological hypothesis. Over the years several ions and radicals have been identified in comet tails, and though it is assumed that these "daughter products" originate through the action of radiation and the solar wind on parent compounds in the nucleus, these latter substances have never been directly identified. The hydroxl radical is an example of a daughter product found in comet tails. Though it has been suggested that it arises from water in the nucleus, an unequivocal identification has not been possible because it could also derive from methanol, a substance known to be a constituent of the interstellar medium. The radicals NH_2 and C_3, first analysed by the NRC Spectroscopy Laboratory, are other examples of molecules identified in comets that can originate from more than one parent compound. With H_2O^+, however, there is very little room for speculation. It could only have come from water. As Dr. Herzberg explains: "This evidence for the presence of H_2O^+ makes it very difficult to conclude otherwise than that neutral H_2O is also present. It is only slightly less direct than the observation of the radio frequency line of water itself." □

Wayne Campbell