and of the grain mass distribution function. But the present results could suggest, for instance, that comet Giacobini-Zinner has very low density grains ("feathers"), in agreement with previous deductions from Giacobinid-meteor observations (*25*).

Impulsive noise. On several occasions, outside the plasma tail, particularly from 1 hour 30 minutes to 1 hour (1.0×10^5 to 0.7×10^5 km) before encounter and from 45 minutes to 1 hour (0.5×10^5 to 0.7×10^5 km) after, the S antenna recorded a noise much above (10 to 10^3 times) the thermal noise level. Figure 6 shows an example. These spectra, which could indicate a high level of turbulence, are reminiscent of data acquired in Earth's magnetosheath; their study has only been started. The presence of this noise prevents us from setting any limit on dust impacts outside the plasma tail.

REFERENCES AND NOTES

1. R. Knoll *et al.*, *IEEE Trans. Geosci. Electron.* **GE-16**, 199 (1978).
2. A. G. Sitenko, *Electromagnetic Fluctuations in Plasma* (Academic Press, New York, 1967).
3. O. De Pazzis, *Radio Sci.* **4**, 91 (1969); A. Andronov, *Kosm. Issled.* **4**, 558 (1967).
4. J. A. Fejer and J. R. Kan, *ibid.* **4**, 721 (1969).
5. N. Meyer-Vernet, *J. Geophys. Res.* **84**, 5373 (1979).
6. P. Couturier, S. Hoang, N. Meyer-Vernet, J. L. Steinberg, *ibid.* **86**, 11127 (1981); in *Solar Wind 5*, A. J. Lazarus and M. Neugebauer, Eds. (NASA Publ. 2280, Woodstock, 1983), pp. 377–383.
7. S. Hoang *et al.*, *J. Geophys. Res.* **85**, 3419 (1980).
8. N. Meyer-Vernet, P. Couturier, S. Hoang, J. L. Steinberg, R. D. Zwickl, *ibid.*, in press.
9. Except if the bulk plasma velocity in the antenna frame induces an important Doppler shift (*8*).
10. This discussion neglects the ambient static magnetic field. If $L/L_D \gg 1$, this requires that the electron gyrofrequency and its lowest harmonics be much smaller than f_p [P. Meyer and N. Vernet, *Radio Sci.* **9**, 409 (1974); D. T. Nakatani and H. H. Kuehl, *ibid.* **11**, 433 (1976); D. D. Sentman, *J. Geophys. Res.* **87**, 1455 (1982)].
11. H. H. Kuehl, *Radio Sci.* **1**, 971 (1966).
12. K. G. Balmain, *J. Res. Natl. Bur. Stand.* **D69**, 559 (1965).
13. If the spacecraft size is smaller or of the order of L_D.
14. All the spectra shown in this report were measured or calculated at the receiver input ports. They are related to the noise spectrum V^2 at the antenna terminals by the transfer gain calculated (*7*) from the receiver and antenna impedances.
15. N. Meyer-Vernet, *J. Geophys. Res.* **88**, 8081 (1983).
16. M. Petit, *Ann. Telecommun.* **30**, 351 (1975).
17. J. G. Laframboise and L. W. Parker, *Phys. Fluids* **16**, 629 (1973).
18. The f^{-2} spectrum assumes that f^{-1} is both smaller than the system time constant and larger than the rise time of the signal; this condition generally holds for the wire S antenna; but it does not hold everywhere for the Z antenna. This also neglects the contribution of the photoelectrons recollected after emission.
19. R. J. L. Grard, in *Proc. 17th ESLAB Symp.* (ESA SP-198, 1983), pp. 151–159.
20. Since the energy is too low for kinetic emission to occur (D. T. Young, *ibid.*, pp. 143–150).
21. This estimation is rather hazardous [R. Schmidt and H. Arends, in *Proc. GIOTTO PEWG Meet.* (ESA SP-224, 1984), pp. 15–19.22].
22. M. G. Aubier, N. Meyer-Vernet, B. M. Pedersen, *Geophys. Res. Lett.* **10**, 5 (1983).
23. D. A. Gurnett, E. Grün, D. Gallagher, W. S. Kurth, F. L. Scarf, *Icarus* **53**, 236 (1983).
24. F. R. Krüger and J. Kissel, in *Proc. GIOTTO PEWG Meet.* (ESA SP-224, 1984), pp. 43–48; E. Grün, *ibid.*, pp. 39–41.
25. N. Divine, JPL Interoffice Memorandum 5137-84-164 (Jet Propulsion Laboratory, Pasadena, CA, 1984). D. K. Yeomans and J. C. Brandt, *The Comet Giacobini-Zinner Handbook* (Jet Propulsion Laboratory, Pasadena, CA, 1985).
26. With an impact rate of 1 sec^{-1}, the probability of an impact for each 0.125-second measurement is 0.125. There are 18 frequency channels below 300 kHz, with five data points each. This yields $0.125 \times 18 \times 5 \approx 11$ points.

27. We are grateful to the team of engineers and technicians, spread on both sides of the Atlantic and led by R. Knoll, who designed, built, tested, and integrated our instrument and made it the most sensitive one ever flown; it is thanks to their hard work, dedication, and competence that we could systematically use the weak thermal noise (10^{-14} V^2 Hz^{-1} is only 4.5 μV in our 3-kHz bandwidth) as a powerful plasma diagnosis tool. Our thanks are also due to the ISEE-3 project team in NASA-GSFC and to the Fairchild team who succeeded in designing, building, and testing a very quiet spacecraft. The French part of the experiment was financed under contract with Centre National d'Etudes Spatiales.

20 November 1985; accepted 4 February 1986

Ion Composition Results During the International Cometary Explorer Encounter with Giacobini-Zinner

KEITH W. OGILVIE, M. A. COPLAN, P. BOCHSLER, J. GEISS

The International Cometary Explorer spacecraft passed through the coma of comet Giacobini-Zinner about 7800 kilometers antisunward of the nucleus on 11 September 1985. The ion composition instrument was sensitive to ambient ions with mass-to-charge ratios in the ranges 1.4 to 3 atomic mass units per electron charge (amu e^{-1}) and 14 to 33 amu e^{-1}. Initial interpretation of the measurements indicates the presence of H_2O^+, H_3O^+, probably CO^+ and HCO^+, and ions in the mass range 23 to 24; possible candidates are Na^+ and Mg^+. In addition to these heavy ions, measured over the velocity range 80 to 223 kilometers per second, the instrument measured He^{2+} of solar wind origin over the range 237 to 463 kilometers per second. The heavy ions have a velocity distribution which indicates that they have been picked up by the motional electric field, whereas the light ions are steadily decelerated as the comet tail axis is approached. These results are in agreement with the picture of a comet primarily consisting of water ice, together with other material, that sublimes, streams away from the nucleus, becomes ionized, and interacts with the solar wind.

SPECTROSCOPIC OBSERVATIONS OF the comas of comets (*1–3*) have indicated the presence of various ionic species. Mass spectrometric measurements of ions in the coma of comet Giacobini-Zinner were made during the encounter of the International Cometary Explorer (ICE) on 11 September 1985, when the spacecraft passed within 7800 km of the nucleus on its antisunward side. For mass-to-charge (M/Q) ratios from 14 to 33 amu e^{-1}, H_2O^+ was the dominant ion; several other species were also detected.

Observations at Venus (*4*) and at Titan (*5*), where flowing plasma interacts directly with a dense atmosphere, have established the modification of the plasma flow field by the formation of ions that picked up momentum from the plasma. The same phenomenon was predicted to occur on a much larger scale in comets (*6*). For Giacobini-Zinner the measurements by the ion composition instrument (ICI) of the velocity distributions of He^{2+} ions, which are diagnostic of the flow field, combined with measurements of the distributions of heavy ions from the comet, confirmed the prediction.

The ICI (*7, 8*) was designed for solar wind measurements and was used to study the composition of the solar wind and the velocity distributions of and velocity differences among solar wind ions (*9*). The ions in the solar wind are highly charged since they retain the charge states acquired in the corona; the appropriate range of values of M/Q normally covered by the ICI was 1.4 to 5.8 amu e^{-1}, measured over a solar wind velocity (V) range of 300 to 620 km sec^{-1}. The ranges of M/Q and V in which observations were made were set by parameters read into the instrument microprocessor through the spacecraft command system. To cover values of M/Q and V appropriate to the comet (where singly charged ions are expected), a set of parameters was found that selected 14 M/Q values between 14 and 33 amu e^{-1} for V between 80 to 224 km sec^{-1} and 14 M/Q values between 1.4 and 3 amu e^{-1} for V between 237 and 463 km sec^{-1}. The dual M/Q range was achieved by causing an overflow condition in the microprocessor calculating the potentials applied to the plates of the energy analyzer, which forms part of the ICI, in a way similar to that used to study ions in Earth's magnetic tail (*10*). The overflow took place for V

K. W. Ogilvie, NASA/Goddard Space Flight Center, Code 692, Greenbelt, MD 20771.
M. A. Coplan, Institute for Physical Science and Technology, University of Maryland, College Park, MD 20742.
P. Bochsler and J. Geiss, Physikalisches Institut, University of Bern, 3012 Bern, Switzerland.

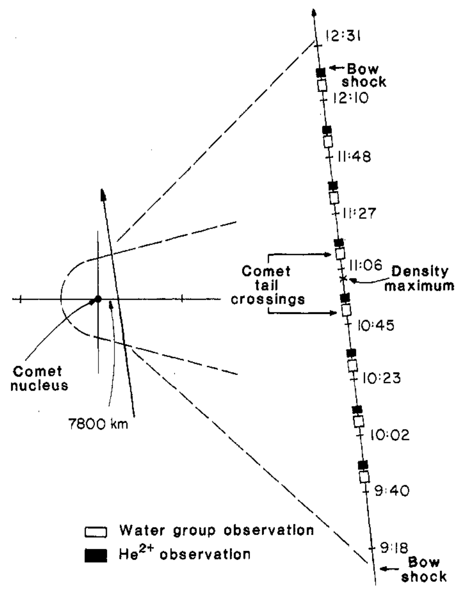


Fig. 1. Diagram (not to scale) of the encounter of ICE with the comet, showing how the spacecraft crossed the comet tail at approximately 7800 km on the antisunward side, almost perpendicular to the sun-comet line. The relative velocity was approximately 21 km sec^{-1}. The trajectory appears to the right on an expanded scale. The times shown along the trajectory are the approximate starting times of the eight scans, which were made about the time of closest approach. The rectangles, which have lengths of ~5000 km for the water-group ions ($17.3 \geq M/Q \geq 19.5$ amu e^{-1} and ~3000 km for He^{2+} ($1.88 \geq M/Q \geq 2.12$ amu e^{-1}), represent the distances traveled by the spacecraft along the trajectory during the corresponding measurements. These distances are several ion gyroradii in most conditions. Suggested positions of bow shock crossings, tail boundary crossings, and maximum electron density derived from other experiments are indicated.

greater than 224 km sec^{-1}, so that it was possible to measure light ions at high V, where He^{2+} forms a convenient tracer of the flow field, and heavy ions at low V. Each combination of M/Q and V was held for one spin of the spacecraft (the instrument was sensitive for the entire spin), and a full scan took 420 spins (21.13 minutes) to complete. A scan over V at a single value of M/Q in the heavy-ion range required approximately 1 minute. The M/Q resolution, $(M/Q)/\Delta(M/Q)$, was in the range 20 to 30 for solar wind observations but depended on the parameter MV/Q and was 11 at M/Q of 33 amu e^{-1} and V of 230 km sec^{-1}.

During the encounter the spacecraft was moving at a speed relative to the comet of 21 km sec^{-1} and crossed its tail almost perpendicularly (Fig. 1). The distances traveled by the spacecraft during each measurement were several times the ionic gyroradius in most conditions along the trajectory. Observations made by the radio science instrument (*11*) showed that the electron density increased sharply midway between the comet tail crossings (Fig. 1); one scan of He^{2+} and two partial scans of the heavy ions were made within the ion tail. In addition, five complete observations were taken outside the tail, but inside the region where the solar wind interacted most strongly with the cometary ions. These observations were approximately symmetrical with respect to the tail axis.

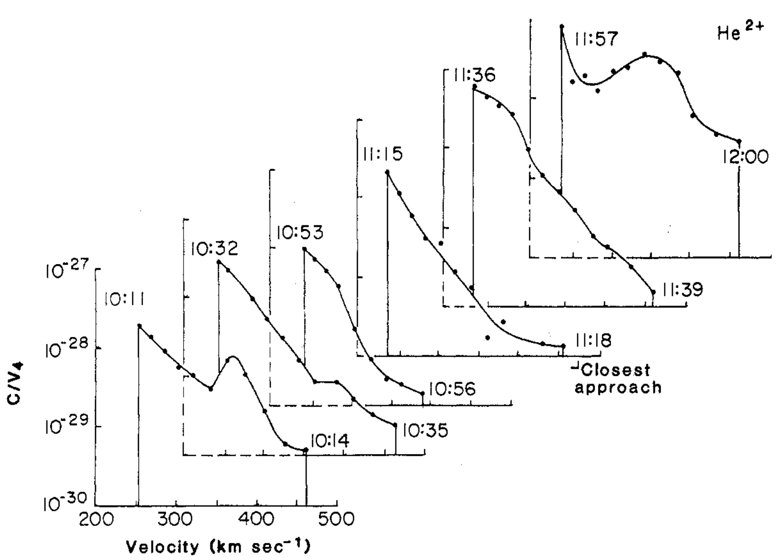
Our measurements show that before encounter the solar wind He^{2+} speed was rising. During the hour starting at 0400 universal time (U.T.) the average He^{2+} speed was 385 km sec^{-1}; just before closest approach it was slightly above the ICI maximum limit for He^{2+} (463 km sec^{-1}). After closest approach, at 1235 U.T., the speed was 435 km sec^{-1} and falling; by 1300 U.T. it was 420 km sec^{-1}.

Ions of cometary origin appeared at the upper limit of the velocity window (223 km sec^{-1}) at about 1026 U.T. (~50,000 km from the tail axis). The velocities of these ions decreased rapidly between 1045 and 1051 U.T., when they began to disappear at the lower limit of the velocity window (80 km sec^{-1}). After the ICE crossing of the central part of the tail, the cometary ions reappeared in strength at 1110 U.T., and they disappeared at the upper limit of the velocity window around 1135 U.T.

We have assumed that the velocity distributions of the ions measured at various positions along the trajectory were uniquely representative of the regions where they were measured; no corrections for density variations during the measurement have been made. This is an admissible first step because the spacecraft traveled only a few ionic gyroradii along its trajectory during a measurement of a single ionic species (Fig. 1).

The major result was that the speed of the solar wind flow was strongly decreased as a consequence of heavy loading by cometary ions. This was illustrated by the velocity distributions for He^{2+} during the encounter (Fig. 2). He^{2+} can come only from the solar wind; even if some helium were to be emitted from the comet, perhaps as a result of previous trapping of the solar wind, it would be present overwhelmingly in neutral or singly charged form.

The velocity distributions of He^{2+} resemble reduced distribution functions; however, since the instrument performs an integration around the spin axis, they are related to the spacecraft equatorial plane rather than



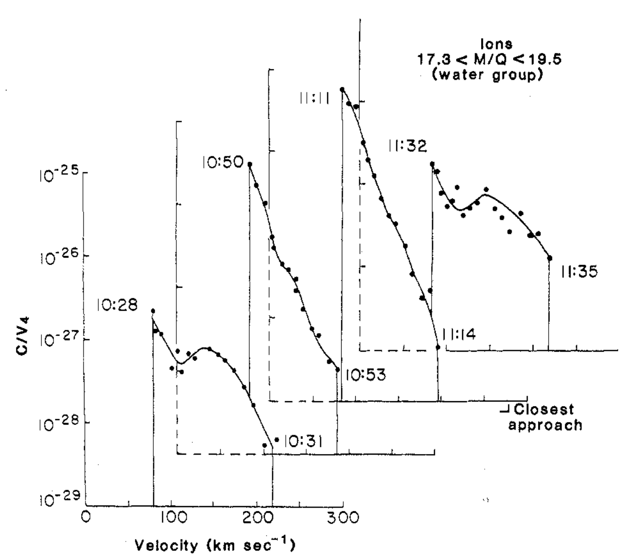


Fig. 2 (left). Velocity distributions for He^{2+} measured at six times during the encounter. Times refer to the start and finish of the parts of the scans when the measurements were made. Fig. 3 (right). Velocity distributions for ions in the M/Q interval 17.3 to 19.5 amu e^{-1}, interpreted as H_2O^+ and H_3O^+. For the scans starting at 1023 and 1127 U.T., the distributions indicate ion pickup at around 150 km sec^{-1}.

the direction of the magnetic field. As a consequence of the high degree of turbulence in the vicinity of the comet observed by instruments with high time resolution (*12*), the distributions may be expected to be isotropic with respect to the plasma rest frame over intervals comparable to the time resolution of this instrument.

The velocity distributions of He^{2+} shown in Fig. 2 can be organized with respect to the axis of the comet tail. The distribution measured at 1011 to 1014 U.T. (some 63,000 km from the axis of the tail) can be matched with that at 1157 to 1200 U.T. (70,000 km), and so forth. The outermost distributions show local maxima at velocities somewhat below that of the solar wind, while those measured at 1032 to 1035 U.T. and 1136 to 1139 U.T. show only shoulders at these velocities, considerably lower in amplitude than the corresponding maxima of the adjacent spectra. The distributions measured at 1053 to 1056 and 1115 to 1118 U.T. show lower phase density at a given velocity than those measured farther from the comet tail axis. This indicates that the solar wind ions were slowing as the comet tail was approached. The absolute maxima of each of the velocity distributions fall below the lowest velocity measured by the ICI (237 km sec^{-1}). The subsidiary regions of positive slope in the outermost spectra suggest the presence of a plasma instability, which is consistent with the large-amplitude ion acoustic and other turbulence observed by other instruments (*13*).

We conclude that appreciable mass loading, similar to that observed at Venus and Titan, occurs on a much larger scale at Giacobini-Zinner to distances beyond 60,000 km from the comet tail axis and that at smaller distances flow speed eventually falls well below 240 km sec^{-1}. These observations are in good qualitative agreement with the results of a simulation of the interaction performed by Fedder *et al.* (*14*) which was made for a solar wind speed of 400 km sec^{-1}.

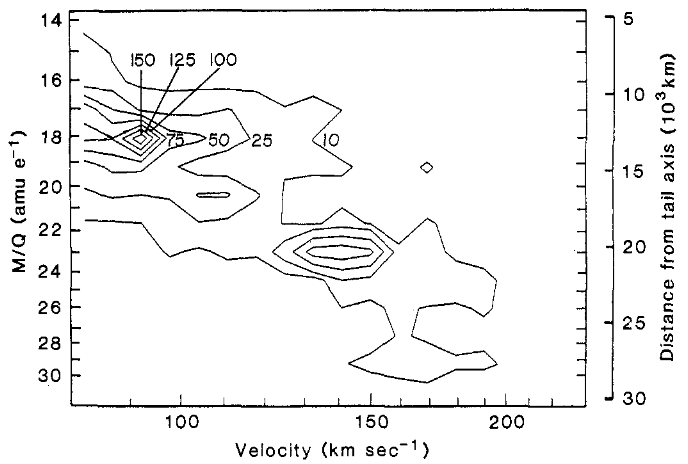


Fig. 5. Contour plot of heavy-ion count rates as a function of M/Q and V for the period 1106 to 1126 U.T. The mass scale is accurate to ± 1 amu e^{-1}. The contours correspond to count rates of 10, 25, 50, 75, 100, 125, and 150 sec^{-1}.

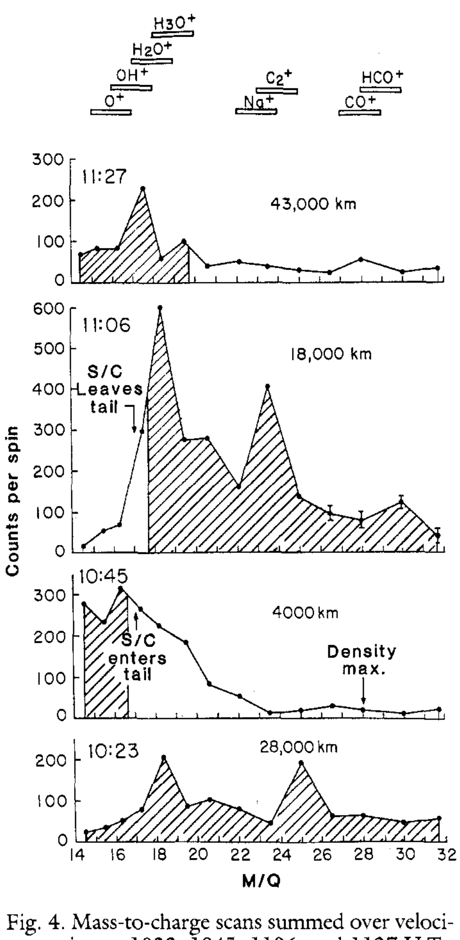


Fig. 4. Mass-to-charge scans summed over velocity starting at 1023, 1045, 1106, and 1127 U.T., respectively. At the top of the figure the positions of likely ionic species are shown. The instrument resolution is indicated by the horizontal bars. The shaded portions of the spectra correspond to those periods during which the ion velocities were within the velocity range of the instrument. The distances given for each scan are the approximate distances of the spacecraft from the comet tail axis during the observation.

We now consider the velocity distribution of the picked-up ions and take as an example those with M/Q values between 17.3 and 19.5 amu e^{-1}, shown in Fig. 1 as the water group. The four velocity distribution plots, corresponding to observations from 1028 to 1031, 1050 to 1053, 1111 to 1114, and 1132 to 1135 U.T. (Fig. 3), were not corrected for density variations. However, only the ones taken around 1050 and 1111 U.T. will be affected by this, since only they overlap to any extent the high-density peak observed in the comet tail. These two distributions show a rise toward lower velocities, indicating that most of the water ions in, or close to the edge of, the tail are moving at less than 80 km sec^{-1}. The distributions taken at 1028 and 1132 U.T. differ in magnitude from those taken closer to the comet tail (1050 and 1111 U.T.). They are one order of magnitude smaller in phase density at low velocities and show a marked local maximum at ~145 km sec^{-1}, which we interpret as resulting from heavy ion pickup. Thus the He^{2+} and the heavy ion observations support one another in a consistent picture of the interaction, in which ion pickup slows the solar wind and the magnetic field becomes draped around the cometary nucleus to form a magnetic tail containing slower plasma.

Let ψ be the angle between the flow direction and the magnetic field, assumed to be in the ecliptic plane. Then an ion picked up by the motional electric field moves in a cycloidal orbit and, during the phase of the cycloid when the ion's motion is in the ecliptic plane, it moves at $2V_{He^{2+}} \sin \psi$; thus

$$\sin \psi = V_{H_2O^+}/2V_{He^{2+}} \quad (1)$$

From Fig. 2, $V_{He^{2+}} \leq 237$ km sec^{-1} and $V_{H_2O^+} \simeq 150$ km sec^{-1}, so that ψ could be as small as 18°. This fits well with the draped magnetic field geometry expected as a result of the mass loading near the comet tail.

As stated above, the mass resolution $(M/Q)/\Delta(M/Q)$ is reduced for heavier ions, and the ICI cannot resolve two ions separated by one mass unit in the range 14 to 33 amu e^{-1}. This introduces some uncertainty into the interpretation; nonetheless, some definite statements can be made about the composition.

In Fig. 4 we show the four low-velocity heavy-ion scans about the distance of closest approach; namely, those beginning at 1023, 1045, 1106, and 1127 U.T., observed during the ICE traversal of the pickup region and the magnetic tail of the comet. There were significant variations in relative composition between these measurements, and care must be taken in their interpretation because of the possibility of changes in density, temperature, flow direction, and speed during a measurement. For example, during most of the scan starting at 1045 U.T., the spacecraft was within the tail of the comet and did not emerge until the scan starting at 1106 U.T. had reached

M/Q = 17 amu e^{-1}. The scan at 1045 U.T. showed very few ions at the higher masses because the plasma flow speed was below the low-velocity threshold of the instrument (80 km sec^{-1}) between 1050 and 1110 U.T. when in the comet tail.

All four scans show peaks in the mass range occupied by ions of the water group (OH^+, H_2O^+, H_3O^+), which were much more abundant than O^+. H_2O^+ appeared to be the most abundant ion in the mass range of the instrument, and we attribute the shoulder on the high mass side of the H_2O^+ peak at H_3O^+. The scan at 1106 U.T. showed a small but significant peak near M/Q = 28 amu e^{-1}, probably due to CO^+ or HCO^+. Both H_2O^+ and CO^+ have been observed spectroscopically in comets (*3*), and H_3O^+ is a prominent constituent in models (*15–17*).

The scans at 1023 and 1106 U.T. show a significant peak at 23.5 to 25 amu e^{-1}. While this could be due to a sudden density fluctuation of at least a factor of 5, this seems unlikely since the spacecraft was well clear of the comet tail at the times of the observations (1038 and 1119 U.T., respectively). The significance of this M/Q peak can be judged from the contour plot in Fig. 5. There is a well-developed and isolated peak at 23.5 amu $e^{-1} \leq M/Q \leq 25$ amu e^{-1} to which more than six different bins in the M/Q versus V plane contribute. The size of this peak relative to that attributed to H_2O^+ makes interpretation difficult, but a possible candidate in this mass range is Na^+. Atomic sodium (23 amu e^{-1}) has been observed in cometary spectra, but, with rare exceptions (*18*), only in comets close to the sun. Although the abundance of sodium is small, the rate of ionization is large, and, once formed, Na^+ has a long lifetime. Thus the relative abundance of Na^+ may be strongly enhanced in comparison to the molecular ions. Another candidate for this peak could be C_2^+ (24 amu e^{-1}); its neutral counterpart is regularly observed in comets, although Giacobini-Zinner has anomalously low abundances of C_2; furthermore, the rate of photodissociation is several times that of photoionization for C_2.

The velocities and velocity widths of the ions in each of the mass peaks are also evident in Fig. 5. The variation of the velocities of the different ions may simply be due to the fact that the ions were sampled at different distances from the tail axis or from their source and thus could reflect differences in ion production rates and subsequent interactions with the ambient flow field. The ion velocity widths are small compared to the mean velocities. To decide whether this is characteristic of the local conditions or is a cumulative effect, information about the direction from which the ions are flowing is needed. The peaks visible in the scans at 1023, 1106, and 1127 U.T. in Fig. 4 show some variations in M/Q position. While some of these variations may be due to changes in the angle between the plasma flow axis and the instrument axis, we do not rule out the possibility that the composition may vary with the distance from the comet axis.

The results obtained by the ICI at the encounter with Giacobini-Zinner show that the comet fits the generally suggested picture of cometary structure and interaction quite well, with the exception of the unexpectedly large peak tentatively attributed to Na^+.

REFERENCES AND NOTES

1. M. A'Hearn, in *Comets*, L. L. Wilkening, Ed. (Univ. of Arizona Press, Tucson, AZ, 1982), p. 433.
2. D. A. Mendis, H. L. F. Houpis, M. L. Marconi, *Fundam. Cosmic Phys.* **10**, 1 (1985).
3. S. Wyckoff, in *Comets*, L. L. Wilkening, Ed. (Univ. of Arizona Press, Tucson, AZ, 1982), p. 25.
4. L. H. Brace *et al.*, in *Venus*, D. M. Hunten *et al.*, Eds. (Univ. of Arizona Press, Tucson, AZ, 1983), p. 778; C. T. Russell and O. Vaisberg, *ibid.*, p. 873.
5. R. E. Hartle *et al.*, *J. Geophys. Res.* **87**, 1383 (1982).
6. A. A. Galeev, T. E. Cravens, T. I. Gombosi, *Astrophys. J.* **289**, 807 (1985).
7. M. A. Coplan, K. W. Ogilvie, P. A. Bochsler, and J. Geiss [*IEEE Trans. Geosci. Electron.* **9** (No. 16), 185 (1978)] described the construction and calibration of the ICI.
8. S. Kunz, P. Bochsler, J. Geiss, K. W. Ogilvie, and M. A. Coplan [*Sol. Phys.* **88**, 359 (1983)] described the use of the ICI for measurements in the solar wind.
9. K. W. Ogilvie, M. A. Coplan, R. D. Zwickl, *J. Geophys. Res.* **87**, 7363 (1982).
10. K. W. Ogilvie and M. A. Coplan, *Geophys. Res. Lett.* **11**, 347 (1984).
11. N. Meyer-Vernet *et al.*, *Science* **232**, 370 (1986).
12. S. Bame *et al.*, *ibid.*, p. 356.
13. F. L. Scarf *et al.*, *ibid.*, p. 377.
14. J. A. Fedder *et al.*, *Eos* **67**, 17 (1986).
15. W. F. Heubner and P. T. Giguere, *Astrophys. J.* **258**, 753 (1980).
16. W.-H. Ip, *Proc. Int. Meet. Giotto Mission* (ESA SP-169, 1981), p. 79.
17. M. L. Marconi and D. A. Mendis, *Astrophys. J.* **282**, 445 (1984).
18. M. Oppenheimer, *ibid.* **240**, 923 (1980).

19. We thank the many persons, especially those associated with the ICE project, who made this highly successful encounter possible, and T. E. Cravens, W.-H. Ip, and M. F. A'Hearn for helpful comments on the manuscript. P.B. and J.G. thank the Swiss National Science Foundation for support.

20 November 1985; accepted 5 February 1986

Plasma Wave Observations at Comet Giacobini-Zinner

FREDERICK L. SCARF, FERDINAND V. CORONITI, CHARLES F. KENNEL, DONALD A. GURNETT, WING-HUEN IP, EDWARD J. SMITH

The plasma wave instrument on the International Cometary Explorer (ICE) detected bursts of strong ion acoustic waves almost continuously when the spacecraft was within 2 million kilometers of the nucleus of comet Giacobini-Zinner. Electromagnetic whistlers and low-level electron plasma oscillations were also observed in this vast region that appears to be associated with heavy ion pickup. As ICE came closer to the anticipated location of the bow shock, the electromagnetic and electrostatic wave levels increased significantly, but even in the midst of this turbulence the wave instrument detected structures with familiar bow shock characteristics that were well correlated with observations of localized electron heating phenomena. Just beyond the visible coma, broadband waves with amplitudes as high as any ever detected by the ICE plasma wave instrument were recorded. These waves may account for the significant electron heating observed in this region by the ICE plasma probe, and these observations of strong wave-particle interactions may provide answers to long-standing questions concerning ionization processes in the vicinity of the coma. Near closest approach, the plasma wave instrument detected broadband electrostatic noise and a changing pattern of weak electron plasma oscillations that yielded a density profile for the outer layers of the cold plasma tail. Near the tail axis the plasma wave instrument also detected a nonuniform flux of dust impacts, and a preliminary profile of the Giacobini-Zinner dust distribution for micrometer-sized particles is presented.

IT WAS ALWAYS ANTICIPATED THAT THE encounter of the International Cometary Explorer (ICE) with comet Giacobini-Zinner would yield important new information about the plasma physics of the solar wind–comet interaction (*1*), but the actual flyby revealed a surprising strength for the interaction and an unexpected size for the coupling region. The ICE plasma wave instrument detected turbulence associated with fluxes of energetic ions in a pickup region that extended more than 4 × 10^6 km from the comet nucleus. As ICE approached to within several hundred thousand kilometers of the nucleus, these turbulence levels

F. L. Scarf, F. V. Coroniti, C. F. Kennel, TRW Space and Technology Group, Redondo Beach, CA 90278.
D. A. Gurnett, University of Iowa, Iowa City, IA 52242.
W.-H. Ip, Max-Planck-Institut für Aeronomie, Lindau, West Germany.
E. J. Smith, Jet Propulsion Laboratory, Pasadena, CA 91109.