DUST PARTICLES DETECTED NEAR GIACOBINI-ZINNER BY THE ICE PLASMA WAVE INSTRUMENT

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Abstract. During the ICE flyby of Giacobini-Zinner the plasma wave instrument detected numerous impulsive signals caused by dust impacts on the spacecraft. Most of the impacts occurred within 30,000 km of the comet. The impact rate averaged over the inbound and outbound legs varies approximately as $1/r^2$, as would be expected for an isotropic constant velocity radial outflow. Small differences between the inbound and outbound legs exist which may be indicative of azimuthal variations in the dust production rate. A simple model of the impact ionization and charge collection by the antenna indicates that the particles have a mass on the order of 10^{-12} to 10^{-10} gm, corresponding to particles with radii of a few microns.

Introduction

During the ICE (International Cometary Explorer) flyby of the comet Giacobini-Zinner on September 11, 1985, the plasma wave instrument detected numerous impulsive electric field signals that are believed to be due to dust impacts on the spacecraft [Scarf et al., 1986]. The purpose of this paper is to present an initial analysis of these impacts.

Dust impact effects of this type were first observed during the Voyager 2 crossing of Saturn's ring plane. During the ring plane crossing both the plasma wave and radio astronomy instruments detected numerous impulsive noise bursts on the electric antenna [Scarf et al., 1982; Warwick et al., 1982]. Subsequent analysis by Gurnett et al. [1983] and by Aubier et al. [1983] led to the conclusion that the impulsive signals were caused by micron-sized particles striking the spacecraft. When a small particle strikes a solid surface at a sufficiently high velocity, the particle is instantly vaporized and ionized. Laboratory measurements show that the charge released is directly proportional to the mass of the impacting particle [for a review, see Fechtig et al., 1978]. Some of the charge released by the impact is collected by the electric antenna, thereby producing a voltage pulse. The amplitude of the voltage pulse is therefore proportional to the mass of the particle.

Overview of Observations

An expanded 16-channel plot of the antenna voltages detected during a representative 2-minute interval near the closest approach to Giacobini-Zinner is shown in Fig. 1. The output of each channel is proportional to the logarithm

of the voltage amplitude with a dynamic range of 90 db, from about 10 μVolt to 0.3 Volt. The output of each channel is processed by a peak detector which discharges exponentially with a time constant of 0.3 sec. The 16 channels are sampled sequentially starting with the 100-kHz channel and ending with the 17.8-Hz channel. The time required for a scan of all 16 channels is 0.125 sec, and a complete spectrum scan is obtained once per second. For a further description of the instrument, see Scarf et al., [1978].

As can be seen from Fig. 1, the antenna voltages are characterized by numerous impulsive events, often extending simultaneously across a broad range of frequencies. Some of these events have a well-defined peak in the spectrum, typically at frequencies from about 1 to 50 kHz. The events at 1107:23, 1107:39 and 1107:49 are of this type. We interpret these broadband bursts as plasma waves. As described by Scarf et al. [1986], numerous impulsive plasma wave emissions of this type were observed near the comet.

Another type of impulsive event, with a more nearly monotonic spectrum, can be seen in Fig. 1 decreasing in intensity with increasing frequency. The events at 1106:31, 1106:43 and 1107:15 are of this type. We interpret these events as dust impacts. Spectrums of these events are shown in Fig. 2. These events are believed to be dust impacts because they are qualitatively similar to the impacts detected by Voyager 2 at Saturn. The power law index, γ, of the spectrum varies from about -2 to -4, with a tendency for the spectrum to steepen at higher frequencies, very similar to the Voyager 2 spectrum given by Aubier et al. [1983]. The ICE spectrums are not as intense as the Voyager 2 spectrums because the
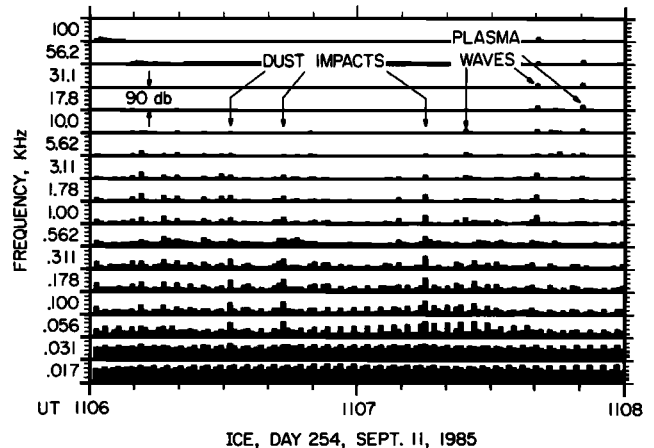

Fig. 1. A 16-channel plot of the electric antenna voltages near closest approach. The sharp spikes extending across all channels from about 31 Hz to 10 kHz are believed to be dust impacts.
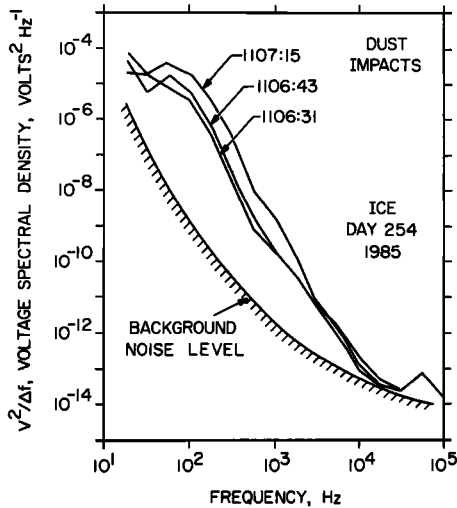
Fig. 2. The spectrum of some selected dust impacts from Fig. 1.

impact rate is not as high (the spectrums in Fig. 2 are single impacts, whereas the spectrum given by Aubier et al. is an average over many impacts), but otherwise are quite similar.

Impact Rate and Number Density

In order to determine the impact rate, a computer algorithm was developed to identify impulsive events. Because of the large dynamic range, the identification criterion was based on the logarithm of the voltage spectral density, I = $\log_{10}(V^2/\Delta f)$. Impulsive events were selected by requiring that the difference between preceding and following intensities, $\Delta I_- = I_n - I_{n-1}$ and $\Delta I_+ = I_n - I_{n+1}$, averaged over the 56.2 Hz through 10-kHz channels, exceed a preset threshold. Channels below 56.2 Hz were not used because of the high interference levels in these channels, and channels above 10 kHz were not used because the impulses are usually below the instrument noise levels at these frequencies. A threshold value of $\Delta I_{th} = 0.2$ was found to give a reliable identification of impulsive events without introducing a large number of spurious events.

To separate impacts from plasma wave emissions a power law fit test was utilized. Again the 56.2-Hz through 10-kHz channels were used. Events were classified as impacts if the power law index (slope of the best straight line fit of I versus $\log_{10}$ f) was in the range $-4.0 < \gamma < -2.5$, and the r.m.s. error of the fit was less than 0.7. This power law fit test was found to give very good discrimination against plasma waves because the spectrum of plasma waves typically has a peak, which gives a very poor fit to a power law. Using this impact identification criterion a total of 294 impacts were identified during the 2-hour period from 1000 to 1200 UT.

Next we consider the counting rate as a function of time. For this analysis it is useful to introduce an amplitude threshold, so that only particles with masses greater than a certain threshold are counted. The r.m.s. amplitude of the voltage pulse can be computed from the area under the spectrum, $V_{rms}^2 = \int (V^2/\Delta f) df$. The counting rate R is shown in Fig. 3 for two thresholds, 1 mVolt, and 10 mVolt. The error

bars give the statistical uncertainty in the counting rate. At closest approach the counting rates range from about 2 to 10 counts per minute depending on the threshold. The rates for the highest threshold, 10 mVolt, are probably the most reliable, because they represent the largest signals. However, even for 1 mVolt, which is near the background noise level, the count rate shows a well-defined peak centered on closest approach, indicating that these events are probably reliable.

The counting rate has also been computed as a function of radial distance from the comet, and is shown in Fig. 4. Because of the low counting rate only impacts greater than 1 mVolt are considered, and the inbound and outbound legs have been averaged together to improve the counting statistics. The results of this analysis show a smooth monotonic decrease with increasing radial distance. The slope of the counting rate profile on the log-log plot is roughly consistent with a $1/r^2$ density variation, which is what would be expected for an isotropic radial outflow of dust from the comet at a constant velocity.

The number density, n, can be computed from the counting rate using the relation

$$R = nUA \ (\tau/T) \ , \tag{1}$$

where U is the relative speed between the particles and the spacecraft, A is the detecting area, and τ/T is a dead time correction due to the discharge of the peak detector. Since the velocity of the dust relative to the comet is small compared to the spacecraft velocity, U is simply the approach velocity which is about 21 km/sec. The dead time correction can be computed from the discharge time constant of the peak detector, $\tau = 0.3$ sec, and the time between samples, T = 1 sec, which gives $\tau/T = 0.3$. The largest uncertainty in the number density arises from the area factor. The detecting area depends on whether the relevant impacts are on the spacecraft body or the antenna. The flyby trajectory is such that the particles arrive at an angle of about 12.8° from the +Z axis of the
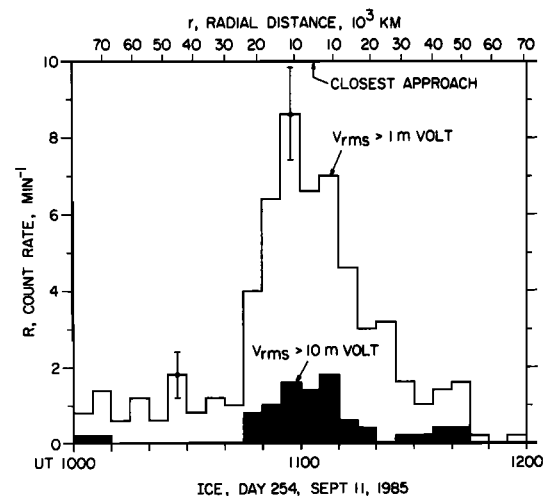

Fig. 3. The counting rate for dust impacts exceeding two thresholds, 1 and 10 mVolt. Most of the impacts occur within 30,000 km of closest approach.
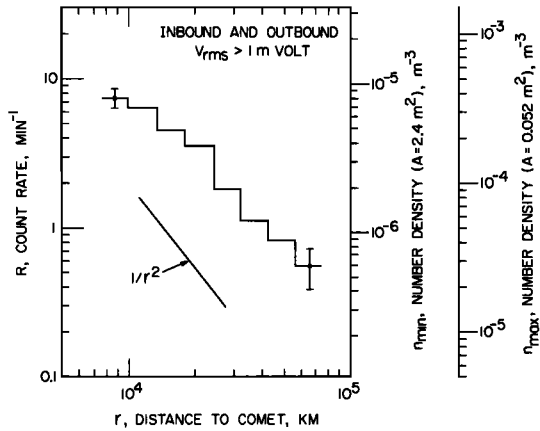

V, is actually larger than the r.m.s. voltage, V_{rms}, computed from the spectrum. For a short pulse the correction factor can be shown to be

$$V = \sqrt{\frac{\Delta t}{\tau_0}} \; V_{rms}, \tag{5}$$

where τ_0 is the duration of the pulse, and $\Delta t = 1/\pi \Delta f$ is the filter response time. From the Voyager waveform measurements a typical pulse duration is known to be a few tenths of one msec [Gurnett et al., 1983]. Since most of the contribution to V_{rms} occurs near 100 Hz (see Fig. 2), Δt is taken to be the response time at 100 Hz. For 100 Hz the filter bandwidth is $\Delta f = 15$ Hz, so $\Delta t \simeq 21$ msec. Assuming a typical pulse duration of $\tau_0 = 0.5$ msec, the correction factor for the filter response is approximately $V \simeq 6.5$ V_{rms}. Although the correction factor depends somewhat on the duration and shape of the pulse, the error involved is probably small compared to the uncertainties in k and α.

Based on the above values the threshold voltages of 1 mVolt and 10 mVolts used in the previous section are found to correspond to masses of $m^* = 1.6 \times 10^{-12}$ and 1.6×10^{-11} gm. Assuming a mass density of 1 gm/cm³, these masses correspond to particles with radii of 0.7 and 1.6 μm. Given that the actual mass is probably somewhat larger than the computed minimum mass, we conclude that the impacts are produced by particles with a radii of a few microns.

Because the particle mass is proportional to the pulse amplitude, the pulse amplitudes provide a direct measurement of the mass distribution. The pulse amplitude distribution, dN/dV_{rms}, integrated over the interval from 1000 to 1200 UT, is shown in Fig. 5. A scale giving the mass, m^*, computed using the previously mentioned parameters, is shown at the top of the diagram. Corresponding particle radii are also given, assuming a density of 1 gm/cm³. This plot shows that the mass distribution has a peak between about 10^{-12} and 10^{-11} gm, and then decreases rapidly with increasing mass, varying approximately as $dn/dm \sim m^{-3}$. The amplitude distribution near 1 mVolt is sensitive to the choice of the counting threshold ΔL_{th}, so the exact shape of the distribution in this region (indicated by a dashed line) is somewhat uncertain.

Discussion

A strong case has been presented that the impulsive antenna voltages detected during the ICE flyby of Giacobini-Zinner are caused by dust impacts on the spacecraft. The radial distribution of the impact rate is roughly consistent with the expected $1/r^2$ density variation for an isotropic radial outflow at a constant velocity, and the size of the particles determined from the pulse amplitudes is consistent with infrared evidence for the existence of micron-sized dust grains near a comet [Hanner, 1984; Divine et al., 1985]. The greatest uncertainty in the present analysis is in the detecting area. With further study we hope to reduce the uncertainty in some of the parameters involved, possibly by combining these measurements with suitable optical and infrared data.

Although the radial variation of the impact rate is generally consistent with a radial outflow model, significant differences do exist between the inbound and outbound legs. For example, the abrupt step in the count rate at 1045 UT on the inbound leg does not appear at a comparable radial distance on the outbound leg. These differences are probably due to azimuthal asymmetries in the dust production rate. Radiation pressure also should affect the dust distribution near the comet. Analysis of these and other effects will require further study.

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