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VOYAGER 2 PLASMA WAVE OBSERVATIONS AT URANUS

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ABSTRACT

At Uranus, the Voyager 2 plasma wave investigation observed very significant phenomena related to radio emissions, dust impacts and magnetospheric wave-particle interactions. On January 19, 1986 (R = 270 R_U) the plasma wave investigation detected an intense radio burst at 31 and 56 kHz, and this provided the first indication that Uranus had a magnetosphere. During the encounter we observed more of these sporadic bursts, along with relatively continuous radio emissions extending down to 10 kHz, and a sporadic narrowband radio signal with f near 5 kHz. As Voyager passed through the ring plane, the plasma wave investigation recorded a large number of dust impacts. The dust ring was relatively diffuse (thickness of several thousand kilometers) and the peak impact rate was near 50 hits/second. The Voyager 2 plasma wave instrument also detected many strong electromagnetic and electrostatic plasma waves, with intensity peaks in the region within 12 Uranus radii. These waves have characteristics that can interact strongly with the local plasma and with the trapped energetic particles, leading to precipitation into the atmosphere, charged particle acceleration, and charged particle diffusion. In addition we detected strong wave activity in the region of the bow shock and moderate levels in the magnetic tail.

INTRODUCTION

The Voyager encounter with Uranus produced a huge amount of exciting new information about the planet and its rings, satellites and magnetosphere. Extensive preliminary reports of measurements from individual instruments were published in the July 4, 1986 issue of Science, where Gurnett et al. /1/ presented the initial description of the plasma wave observations at Uranus. Here we review some aspects of the preliminary discussion and summarize several more recent studies.

URANUS RADIO EMISSIONS AND BOW SHOCK

As the Voyager 1 and 2 spacecraft move away from the Sun, the local solar wind plasma density declines with an inverse square falloff, and the electron plasma frequency falls linearly. This is shown in Figure 1, and it can be seen that as R increases, the window for detection of radio waves keeps expanding down into the plasma wave frequency range. By the time Voyager 2 reached Uranus in early 1986, the nominal lower boundary of the window was near 1 kHz, so that, in principle, radio emissions could have been detected in the upper 8 channels of the 16 channel spectrum analyzer as well as in the waveform receiver, which covers the range 50 Hz to 14 kHz (see the left side of Figure 1). In fact, during the inbound pass, no strong radio emissions were detected until January 19, when Voyager was at a distance of 270 R_U. Gurnett et al. /1/ showed that these initial signals appeared in the 31 and 56 kHz channels of the plasma wave analyzer.

The upper part of Figure 2 has a display of the 16 channel data from a period early on January 24, and here strong radio emissions are again evident only in the 31 and 56 kHz channels, although weaker bursts were clearly detected in the 10 and 17.8 kHz channels too. The intense and sporadic noise bursts shown in the 1.78 and 3.1 kHz channels are electron plasma oscillations associated with proximity to the bow shock, which was crossed at about 0730. The shock crossing was characterized by (1) a clear jump in the magnetic field strength, as shown in the bottom panel (adapted from Ness et al. /2/), and by (2) detection of a diffuse region with strong broadbanded plasma turbulence. It appears that this inbound shock crossing was diffuse because solar wind conditions were somewhat variable at this time; several of the outbound bow shock crossings had turbulence regions that were much thinner than the one shown here.

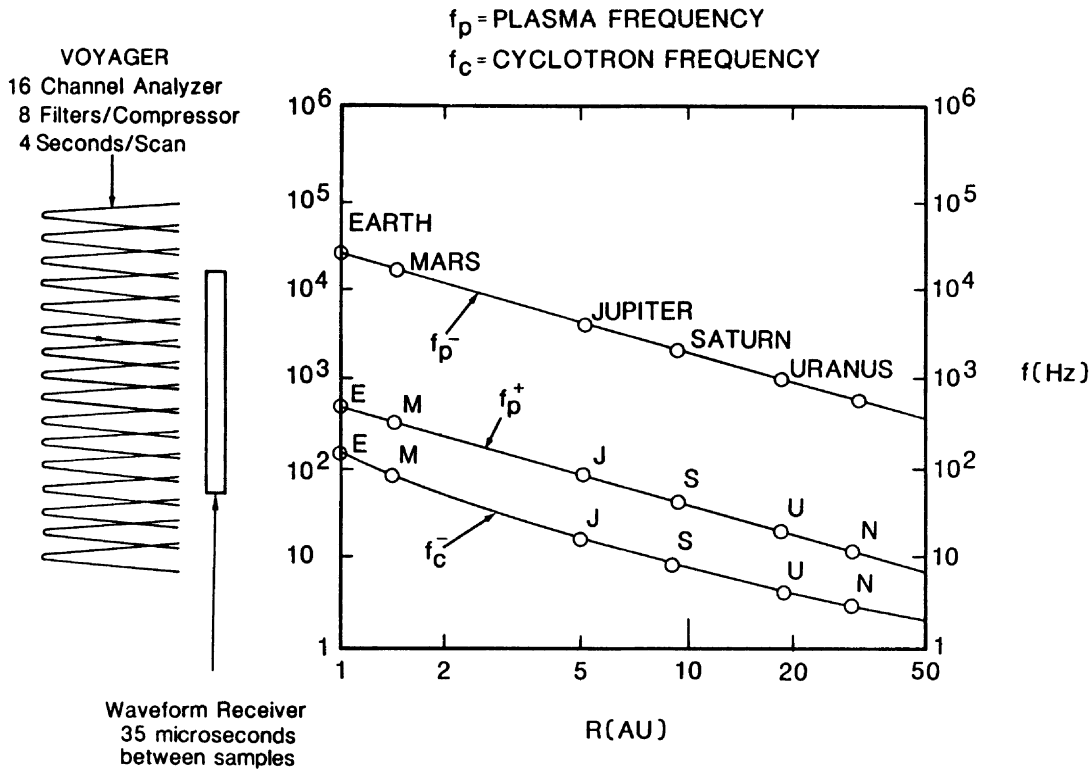

Fig. 1. Right side: Variation with distance of characteristic interplanetary plasma frequencies for nominal solar wind conditions. Left side: Measurement capabilities of the Voyager plasma wave system.

THE INNER MAGNETOSPHERE

Figure 3 shows 16 channel spectrum analyzer data for a seven hour period centered near closest approach to Uranus. For each filter channel the amplitude variation from top to bottom is four orders of magnitude. The curve labeled f_c gives the electron cyclotron frequency derived from the measured B-field magnitude /2/, and the f_p points represent electron plasma frequency values derived from the plasma probe observations /3/. The lower hybrid resonance frequency, f_{LHR}, is derived from f_c and f_p.

The top panels in Figure 3 show that the strong Uranus radio emissions clearly extended down to at least 10 kHz, and Kurth et al. /4/ recently demonstrated that a singular narrowband emission with f near 3-5 kHz was sporadically detected throughout the outbound pass. However, Figure 3 shows that the strongest signals detected during the Uranus encounter were of two types: (1) intense low frequency noise measured in the region of the ring plane crossing, and (2) very strong turbulence with f on the order of $f_c/4$ to $f_c/10$.

An expanded view of the ring plane crossing wave observations is shown in Figure 4. The signals are clearly very intense and the spectrum is quite broadbanded. The amplitude profiles in Figure 4 contain a suggestion that individual impulses were present, and Gurnett et al. /1/ used the waveform data to demonstrate that Voyager 2 was actually detecting many individual dust impacts, just as Voyager 2 did during the Saturn ring plane crossing. In a subsequent analysis, Gurnett et al. /5/ demonstrated that the peak dust impact rate for Uranus was near 50 hits/second, and they showed that the impact profile was not symmetrical about the time for the nominal ring plane crossing. Clearly the plasma wave observations during the ring plane crossing provided unique and significant information on a previously undetected dust ring of Uranus.

We identify the other strong plasma waves as whistler mode emissions. Figure 4 shows a marked asymmetry in wave amplitude with respect to closest approach location, and it is evident that much more intense whistlers were detected during the outbound pass. Krimigis et al. /6/ demonstrated a similar asymmetry in the flux of energetic electrons, and it appears that Voyager traversed a region with very strong wave-particle interactions on the nightside of Uranus. These very intense nightside whistlers have average f/f_c values approximately equal to 0.2, and in this respect they resemble terrestrial chorus emissions. However, analysis of the high-resolution waveform records shows that only the weaker noise bursts detected near closest approach have the classical rising tones associated with

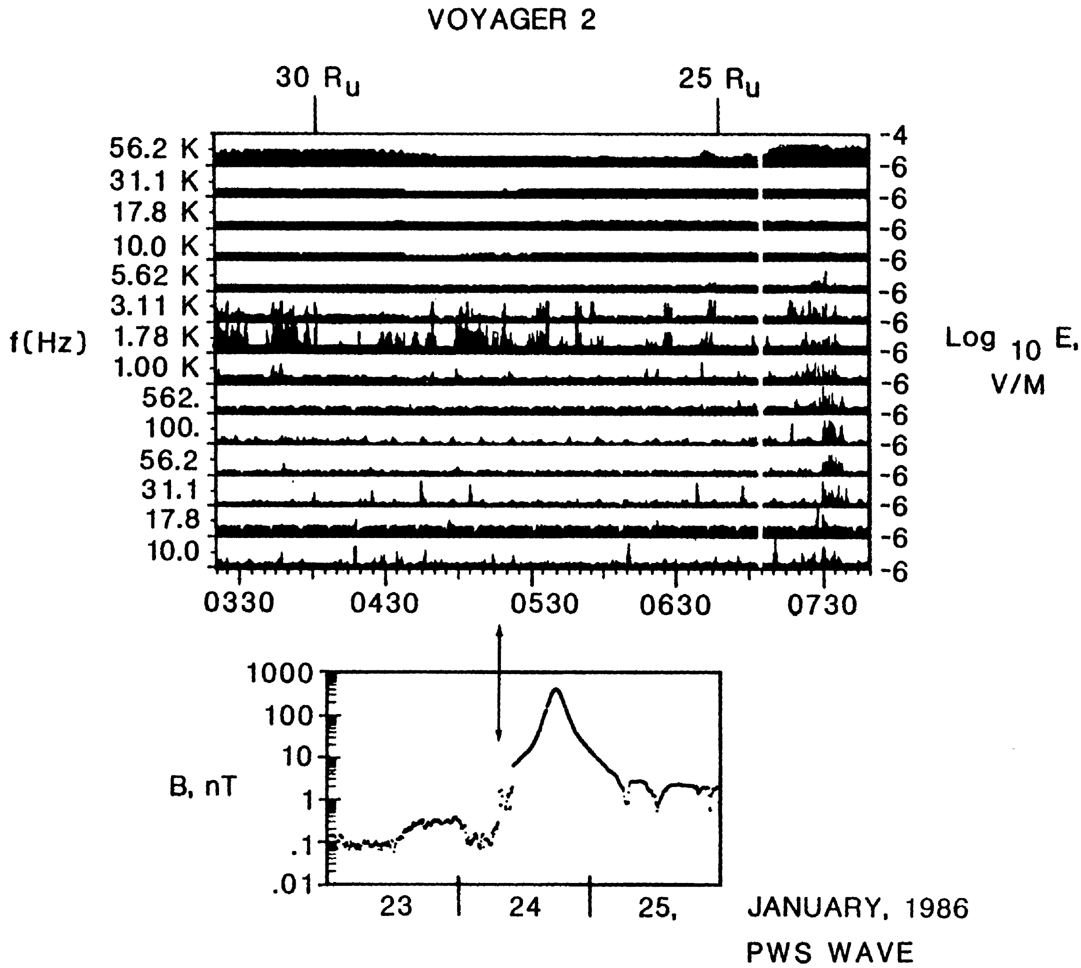

Fig. 2. Lower panel: Summary B-field profile adapted from the initial report on the Voyager 2 magnetometer observations /2/. The vertical arrow marks the inbound bow shock crossing. Upper panel: 16-channel plasma wave measurements showing strong radio emissions (31, 56 kHz data), upstream electron plasma oscillations (1.78, 3.1 kHz data) and broadband turbulence at the shock crossing (near 0730).

chorus. Although the f-t diagrams made up from the waveforms recorded at 1946 UT and 2035 UT show much structure, this structure is irregular with many falling tones. Since Voyager was relatively far from the magnetic equator at these later times, it is quite possible that conventional chorus dispersion characteristics would be strongly distorted by propagation from the source region.

Coroniti et al. /7/ recently analyzed the pitch angle scattering associated with these strong whistler mode emissions. Figure 5 has a high resolution spectral plot made up from a waveform sample recorded when Voyager 2 was just beyond 7 R_U. The labels on the figure essentially show that the scattering resulted in strong diffusion, with considerable energy precipitation into the atmosphere of Uranus.

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A remarkable aspect of the data displayed in Figure 3 is the extensive gap in the whistler mode emission that occurred in an interval centered about 1930 UT. In this region we detected very impulsive signals having many characteristics of ion acoustic waves. The magnetometer /2/, plasma probe /3/, and energetic particle investigations /6,8/ associated this region with the crossing of the Miranda L-shell, and it is tempting to assume that these highly unusual variations in plasma wave characteristics were somehow related to the presence of Miranda. However, at present we have no definitive understanding of the change in wave activity detected in this gap.

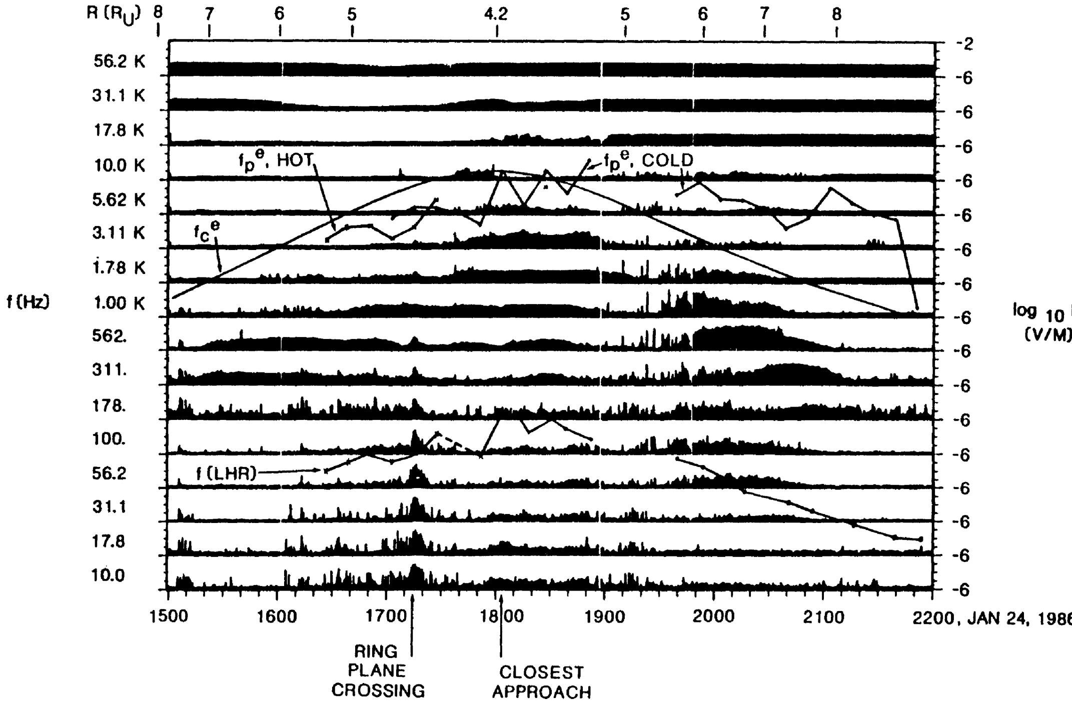

Fig. 3. Summary of plasma wave observations in the inner magnetosphere of Uranus. See text for discussion.

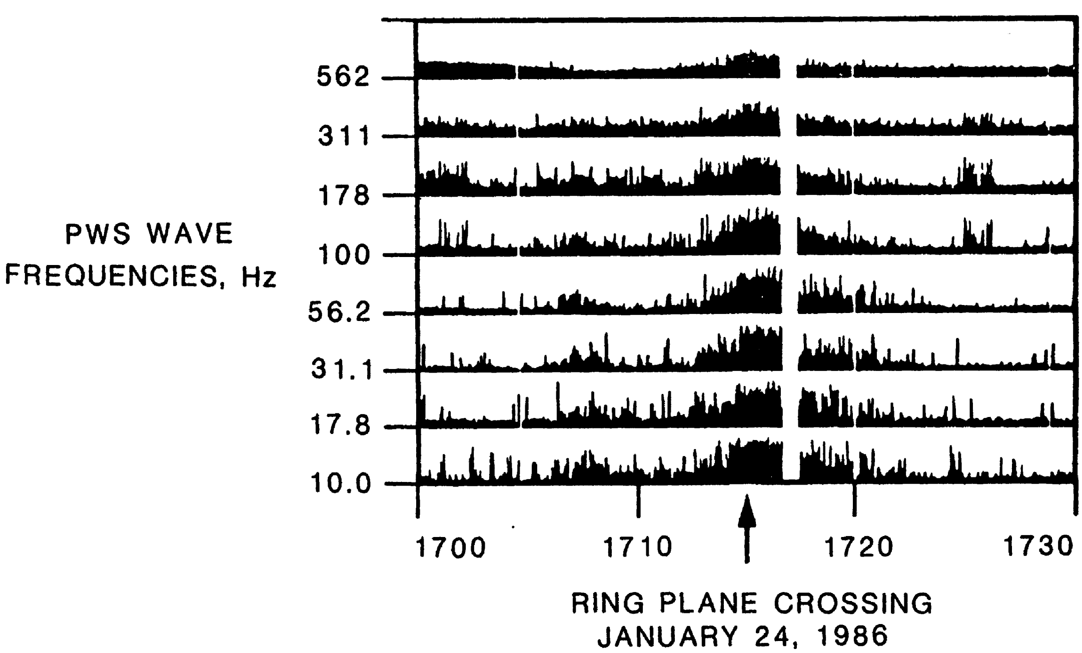

Fig. 4. Expanded view of the low frequency observations associated with detection of the Uranus dust ring.

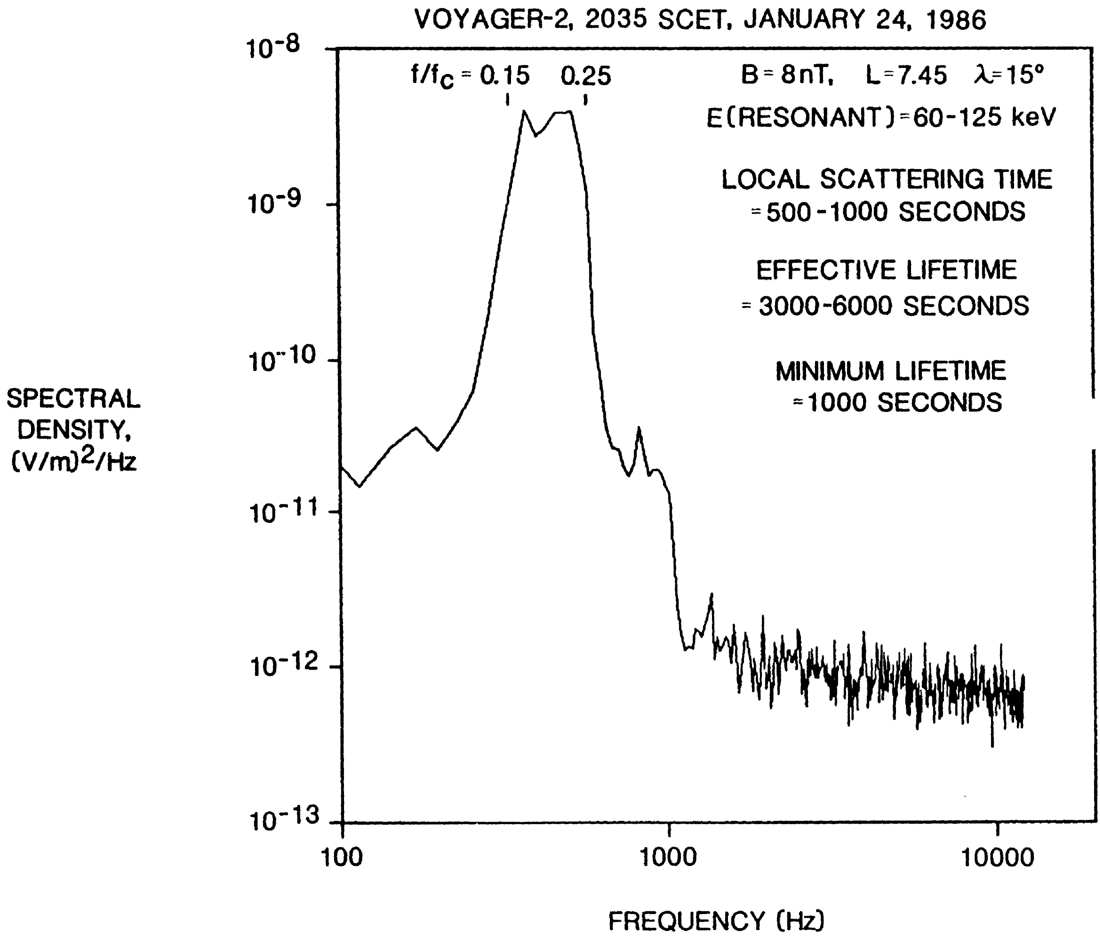

Fig. 5. Spectral density plot made up from high resolution waveform data. These whistler mode emissions interact strongly with the energetic electrons trapped in the Uranus magnetosphere, causing pitch-angle scattering and precipitation into the atmosphere.

COMMENTS

From the point of view of plasma physics, the Uranus magnetosphere appears to have characterestics that are unique and fascinating. At Uranus the plasma wave system detected: (1) a variety of radio emission phenomena; (2) very strong wave-particle interactions associated with whistler mode emissions, and (3) impulsive auroral-type wave activity near the Miranda L-shell. Future correlation studies with data from other Voyager 2 investigations should provide detailed information on the dynamics of the Uranus system.

ACKNOWLEDGMENTS

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