Detection of Bernstein wave forbidden bands
in the Jovian magnetosphere: A new way to measure the electron density

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Abstract. We analyze the power spectra measured by the radio receiver of the Unified Radio and Plasma Wave experiment on Ulysses during its passage through the Jovian inner magnetosphere from ~ 9 \( R_J \) in the outskirts of the Io plasma torus to ~ 13 \( R_J \) near the plasma sheet. Below the plasma frequency \( f_p \), these spectra are weakly banded between gyroharmonics. These observations were interpreted by Meyer-Vernet et al. [1993] as quasi-thermal fluctuations in Bernstein waves. We show that above \( f_p \) each observed gyroharmonic band falls off very abruptly on its high-frequency side. We interpret it as the "forbidden band" predicted by the Bernstein wave dispersion equation between the so-called \( f_Q \) frequency and the consecutive gyroharmonic, that is, a region where no Bernstein wave can propagate. This allows a determination of the local cold plasma frequency and thus of the core electron density with a ~ 16% uncertainty. As a consistency check, we show that the \( f_Q \) thus determined are very close to the frequencies of the resonances excited by the relaxation sounder on Ulysses.

1. Introduction

On February 8, 1992, Ulysses traversed the magnetosphere of Jupiter. That spacecraft carried the Unified Radio and Plasma Wave (URAP) experiment [Stone et al., 1992a], including a low-frequency receiver which was connected to a 2x35 m wire dipole antenna and swept the frequency range 1.25 to 48.5 kHz in 128 s through 64 equally spaced frequency channels of 0.75 kHz bandwidth. The URAP spectra show weakly banded emissions between consecutive gyroharmonic frequencies. These observations were interpreted by Meyer-Vernet et al. [1993] as quasi-thermal noise (QTN) in Bernstein waves [Sentman, 1982]. This interpretation was confirmed by Moncuquet et al. [1995], who derived from the spectra acquired in the Io plasma torus (~ 7 to ~ 9 \( R_J \)) a number of dispersion curves in very good agreement with the theoretical dispersion characteristics of Bernstein modes in a stable plasma, from which the electron temperature was derived.

Here we shall focus on the spectra acquired between ~ 9 \( R_J \) and ~ 13 \( R_J \) on a quasi-radial spacecraft trajectory at ~ 2 \( R_J \) from the centrifugal equator. The magnetic field was decreasing as the Ulysses distance \( R \) to Jupiter increased [Balogh et al., 1992], so that each spectrum contains several (3 to 10) gyroharmonic bands. As \( R \) increased, the plasma frequency \( f_p \) decreased, bringing inside our spectral range some features linked to the \( Q \) resonances (hereinafter noted \( f_Q \)) predicted by Bernstein dispersion theory in each intra-harmonic band above \( f_p \).

In section 2, we briefly review the theory of the \( f_Q \) resonances. In section 3, we show how these resonances and the absence of Bernstein waves propagation at higher frequencies result in an abrupt drop of the voltage power spectrum. These features are used in section 4 to measure the \( f_Q \) and deduce \( f_p \). We finally compare in section 5 the resonance frequencies determined here with those measured by the Ulysses relaxation sounder experiment.

2. Theoretical Bernstein Q Resonances

Bernstein waves are electrostatic waves, sustained by the electron gyration in the ambient magnetic field \( \mathbf{B} \),
which propagate without damping between gyroharmonics, perpendicular to \( \mathbf{B} \)  \((k \equiv k_\perp \) hereinafter, see section 4.4). Their wavelength is of the order of \( 2\pi \) times the electron gyroradius. True Bernstein waves [Bernstein, 1958] correspond to the ideal case of a Maxwellian electron plasma described by the Vlasov equation. However, the electron velocity distribution in the Io torus cannot be accurately fitted by one Maxwellian [Scudder et al., 1981] and was not measured by Ulysses in this region. Hence, following Sittler and Strobel [1987], we shall use the convenient distribution made of two Maxwellians, describing hot and cold populations. Since the measured electrostatic field is very stable, without sporadic emissions, and the level is compatible with QTN in a stable plasma, we do not consider complex unstable distributions (see section 4.4).

With such a core plus halo distribution, the Bernstein’s dispersion equation is

\[
\epsilon = 1 - \sum_{c,h} \frac{\omega_p^2}{\Omega^2} e^{-k_\perp^2 \rho_{c,h}} \sum_{p=-\infty}^{\infty} \frac{p I_p \left( k_\perp^2 \rho_{c,h}^2 \right)}{\omega / \Omega - p} = 0
\]

(1)

where \( I_p \) is a modified Bessel function of the first kind and \( \Omega = 2\pi f_\Omega \) the angular gyrofrequency. Here \( n_{c,h} (\propto \omega_p^2) \) and \( \rho_{c,h} \) are the density and the thermal electron gyroradius, respectively, of each population \((c, h)\).

Figure 1 shows some examples of Bernstein wave dispersion curves computed from (1) in the range \([f_\Omega, 5f_\Omega]\) with \( f_\Omega = 3.1f_\Omega \), which is typical of the spectra observed by Ulysses between \( \sim 9 \) and \( \sim 13 \) \( R_J \), and \( n_h/n_c = 10\% \) and \( T_h/T_c = 25 \), which is of the order of the values measured by Voyager 1 in that region [Sittler and Strobel, 1987]. The \( f_\Omega \) resonances are the finite solutions of the dispersion equation (1) where the group velocity \( V_g = \partial \omega / \partial k_\perp \) vanishes (except the solution at \( k_\perp = 0 \), which is the upper hybrid frequency \( f_{\text{UH}} \)). As is well known [see, e.g., Belmont, 1981], the presence of the hot population may bring about a secondary resonance (noted \( f_{\Omega n} \) in the \( n \)th intraharmonic band) which occurs, in the parameter ranges considered here, below the \( f_{\Omega n} \) linked to the main cold population. We also show as thin lines in Figure 1 Doppler shifted dispersion curves occurring in the frame of an antenna with a relative velocity \( v \). These curves were computed by substituting for \( \omega \) the term \( \omega \pm k_\perp v \) in (1), using \( v \approx 100 \text{ km/s} \) as measured by Stone et al. [1992b] and \( T_c \approx 10^5 \text{ K} \) as measured by Moncuquet et al. [1995] near \( 9 \) \( R_J \); they bracket the solutions of (1) contributing to the QTN (see section 3).

In the \( f_{\text{UH}} \) gyroharmonic band and in the bands above, there always exists a “forbidden band” for Bernstein modes, that is, where (1) has no solution in the absence of Doppler shift. That band is located between \( f_{\Omega n} \) and the consecutive gyroharmonic \((n + 1)f_\Omega \). In the presence of a Doppler shift, the largest \( f_{\Omega n} \) occurs at a slightly lower frequency (noted \( f_{\Omega n+D_s} \) hereinafter), and the band is not fully forbidden since modes of very large \( k_\perp \) exist. However, this band is forbidden for resonant modes (note that its upper limit may be just below the gyroharmonic, since the \( f_{\Omega n+1} \) can be slightly shifted below \((n + 1)f_\Omega \)). These forbidden bands are shown as grey strips in Figure 1.

3. Quasi-Thermal Noise in Bernstein Waves

The calculation of the QTN in Bernstein waves [Sentman, 1982] can be generalized to the case where the dispersion equation has multiple solutions. In that case, using (22) of Meyer-Vernet et al. [1993], we deduce an approximate expression for the noise measured by an antenna in the plasma frame

\[
V_\omega^2 \approx \sum_{k_\perp} \left[ \frac{(\Omega/\omega)\Delta k_{\parallel} / k_\perp}{\partial\epsilon_r / \partial k_\perp \rho c |_{\epsilon_r=0}} \right] \frac{k_B T_h}{\Omega \rho c} \frac{F_{\perp}(k_\perp L \sin \theta)}{4\pi \epsilon_0}
\]

(2)

where \( k_\perp \) denotes the multiple solutions of Bernstein’s dispersion equation for the angular frequency \( \omega \), \( L \) is the antenna length (35 m), \( \theta \) is the angle between the antenna and \( \mathbf{B} \), \( F_{\perp} \) is the antenna response to Bernstein waves, \( \epsilon_r \) is the real part of the dielectric function, and \( k_B \) is Boltzmann’s constant. Since the antenna moves with respect to the plasma, we must add to (2) an integration over the direction of \( k_\perp \) with respect to \( \mathbf{v} \), involving the solutions of the Doppler-shifted dispersion equations [Moncuquet et al., 1995]. The term \( \Delta k_{\parallel} \) is the (small) range in parallel wave vector for which the hot population makes a dominant contribution to the QTN. This term vanishes at gyroharmonics where

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**Figure 1.** Example of Bernstein waves forbidden bands (grey strips). The dispersion curves in the plasma frame are plotted as thick lines, the Doppler-shifted ones are plotted as thin lines. The resonances (\( V_g = 0 \)) are indicated by dots. The locus of all \( f_{\Omega n} \) contributing to the quasi-thermal noise level is shown as a segment from \( f_{\Omega n-D_s} \) to \( f_{\Omega n+D_s} \).
thermal electrons damp Bernstein waves, resulting in the well-defined noise minima observed at gyroharmonics during the Io torus traversal [Meyer-Vernet et al., 1993].

Equation (2) does not hold near resonant solutions where \( |\delta \epsilon_r/\delta k_\perp| = |V_\theta \delta \epsilon_r/\delta \omega| \to 0 \). In this case, the spectral density increases until the first-order approximation of \( \delta \epsilon_r \) used to derive (2) breaks down [Sentman, 1982], then the maximum voltage is set by the second derivative \( \delta^2 \epsilon_r/\delta k^2 \). Here we shall not try to compute \( V_\theta^2 \) at resonances (below we show it is not necessary), but we note that since the energy flux is expected to remain constant, the noise level should continue to increase as the group velocity vanishes, reaching a maximum at resonances. Equation (2) and the above remark allow us to summarize two important properties of the QTN, which the observed spectra should exhibit: (1) In the upper hybrid gyroharmonic band, the spectral density \( V_\theta^2 \) should reach high levels at each resonance and in some frequency band around it, since the \( f_Q \) and \( f_{nQ+Ds} \) peaks are smoothed out by the Doppler shift corresponding to different \( k_\perp \) directions. Note that since \( F_\perp \) vanishes for small argument \( (F_\perp(u) \equiv 0(u^2)) \), the peak at \( f_{UH} \) (where \( k_\perp = 0 \)) could be attenuated, and if the range of variation of \( \theta \) is large enough, the noise should be spin modulated. (2) The signal should plummet in the forbidden bands between the largest Doppler-shifted \( f_{Qn+Ds} \) of the considered harmonic band and \( (n + 1)f_g \) (or slightly below that gyroharmonic, because of the Doppler shift as explained in section 2).

4. Observations and Discussion

Both of the above properties are systematically observed in our data (see Figures 2a and 2b (top)). This allows us to locate the largest \( f_{Qn+Ds} \) resonance in each observed harmonic band: a check of self-consistency can be made by comparing the different \( f_Q \) resonances, using the theoretical Doppler-shifted dispersion curves, which are plotted, in the same frequency range, under

![Figure 2a. Two power spectra at 1912 and 1931 UT showing abrupt drops together with the corresponding dispersion curves and the derived \( f_{Pe}/f_g \).](image)

(top) The solid line is the average of individual measurements (dots) over a frequency step (i.e., 4 measurements acquired in 2 s). The abrupt drop of the signal level at \( f_{Q3+Ds} \) is indicated by an arrow. The variation of \( \sin^2 \theta \) is plotted at the top with its minima indicated as vertical dotted lines. (bottom) Dispersion curves computed by fitting the values of \( f_{Q3+Ds} \) to the observed abrupt drop frequencies are shown; they are plotted with fixed \( n_i/n_e = 0.1 \) and various \( T_i/T_e \) (10, 15, 25, 35, and 50). Note that \( f_{Q3+Ds} \) which defines the low-frequency side of the forbidden band (grey strip), is only a function of \( f_{Pe} \). The gyrofrequency \( f_g \) is deduced from the magnetometer data at the time of the signal drop.
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Figure 2b. Two power spectra at 1944 and 2008 UT, showing the abrupt drops (top) and the dispersion curves (bottom) with the forbidden bands (grey strips), plotted as in Figure 2a with the same notations. Since \( f_g \) was lower than for the spectra shown in Figure 2a, we observe an additional intraharmonic band \([4f_g, 5f_g]\) including the resonance \( f_{Q4+D_s} \) which defines the low-frequency side of a second forbidden band.

each spectrum of Figures 2a and 2b. The abrupt drop
of the spectral density is actually observed in about
80% of the spectra acquired by Ulysses between 1800
and 2300 UT. Because (1) contains \( f_p \), this detection
of a high noise level band (where multiple resonances
occur), abruptly followed by the forbidden band where
\( V \) is low, will allow us to determine the plasma density
in a number of spectra. The problems to be solved are
first to clearly identify the detected \( f_Q \) and then to de-

erve from that detection the plasma frequency or more
exactly the cold plasma frequency as discussed below.

4.1. Identifying the Q frequency

What does "abrupt drop" mean? This needs to be
defined because the frequency and time resolution of the
receiver are limited and because we do not know the sig-
nal level enhancement at the resonance frequencies. We
shall consider that the signal plummets if its decrease is
much larger (in spectral density) and much sharper (in
frequency) than the attenuation due to the antenna re-
sponse \( F_r(k, L \sin \theta) \) and to the damping of Bernstein
modes observed at low-order gyroharmonics where no
forbidden bands exist. During the period under study,
the instrument operating mode was such that the an-
tenna response was poorly known and differed from that
calculated by Meyer-Vernet et al. [1993]. However, one
can see in Figures 2a and 2b that the variation in \( V \)
at the abrupt drop is about a factor 100, that is, at
least 10 times larger than any periodic effect due to the
antenna spin. Each spectrum can include several gy-
roharmonic bands containing forbidden bands and can
thus exhibit multiple signal drops (see Figure 2b). Since
we detect the abrupt drop by comparison with the sig-
nal variations in the low-order gyroharmonic bands, we
will interpret the lowest detected abrupt drop frequency
as the Doppler shifted \( f_{Q4+D_s} \) in the lowest gyro-
harmonic band where these resonances can theoretically
occur (that is the band of \( f_{\text{ULH}} \)).

4.2. Deducing the Electron Density

Equation (1) shows that the \( f_Q \) frequencies are in-
dependent on the core temperature \( T_c \). To show how
the other parameters of the distribution affect the solu-
tions of the dispersion equation and thus the determina-
tion of the plasma frequency from the \( f_{Q4+D_s} \), we have
plotted (Figure 3) a set of dispersion curves with \( f_p \)
(and therefore \( n_e \)) held constant and the suprathermal
electron parameters values chosen in the wide ranges:
0.01 < \( n_A/n_e < 0.25 \) and 10 < \( T_A/T_e < 50 \). One can
see on Figure 3 that the largest Doppler-shifted \( Q \) res-
Figure 3. Examples of dispersion curves for four halo velocity distributions: \( n_h/n_c = 0.01 \) or \( 0.25 \) and \( T_h/T_c = 10 \) or \( 50 \); \( n_c \) is constant. The symbols have the same meaning as in Figure 1. The \( f_{Q''} \), which are linked to the hot population, always arise (in the sampled parameters range) below the \( f_{Q'n+D_s} \), which is roughly independent on the hot population (as the resonance in each band is never the \( f_{Q''} \), and that \( f_{Q'n+D_s} \) is nearly independent of the sampled halo parameters, so that the forbidden band lower limit that we detect is only a function of \( n_c \). We can then determine \( f_{pc} \) by fitting the calculated \( f_{Q'n+D_s} \) to the frequency at which the signal plummets (as shown in Figures 2a and 2b (bottom)); as long as the halo parameters remain in the above ranges, our method yields the core population density.

4.3. Uncertainty on the Doppler Shift

The above determination is a weak function of the assumed Doppler shift, which depends on the corotation velocity and the electron temperature. How far do the uncertainties on these parameters affect the determination of the \( f_{Q'n+D_s} \)? The relative uncertainty due to the Doppler shift at a given frequency \( f \) is

\[
\Delta f/f \simeq \Delta (k \parallel v)/\omega = k \parallel \rho_c (f_0/f) \Delta (v/v_{th})
\]

where \( v_{th} = \sqrt{k_B T_e/m_e} \). In the outer torus, the corotation velocity slightly lags strict corotation [Hill, 1980]. With large parameter ranges bracketing the expected values, 100 km/s \( \lesssim v \lesssim 120 \) km/s and \( 5 \times 10^4 \) K \( \lesssim T_e \lesssim 5 \times 10^5 \) K, we obtain \( \Delta (v/v_{th}) \lesssim 0.05 \). Note that \( T_e \) is expected to increase with latitude [Meyer-Vernet et al., 1995], so that 0.05 is probably an upper limit. We deduce that the cold plasma frequency is determined with a 5% relative accuracy, to which a 3% uncertainty must be added because of the limited frequency resolution of the receiver.

4.4. Consistency of the Interpretation

We have interpreted our observations as QTN in Bernstein mode, following the works of Meyer-Vernet et al. [1993] and Moncuquet et al. [1995]. Since, however, we are studying here a different region of the jovian magnetosphere, the consistency of this interpretation needs to be further justified.

First, the assumption of plasma stability stems from the observational fact: the ratio between the signal maxima and minima as a function of time is roughly constant; the absolute minima take place always close to a gyroharmonic at a level compatible with QTN, and the absolute maxima take place in most cases at the expected Bernstein wave resonances. It is difficult to imagine that an unstable distribution could yield the roughly constant amplitude observed during about 5 hours. Otherwise stated, we have no evidence in our data of distributions able to drive conspicuous instabilities, although Ulysses was in the vicinity of the jovian plasma sheet (at least until 13 Rj from Jupiter and at \( 12^\circ \) magnetic latitude).

Second, the assumption that we are dealing with Bernstein modes (\( k \perp B \)) between the gyroharmonics not only explains the abrupt drops observed in the radio spectra; it is also consistent with the observed spin modulation of the peaks. Indeed the fact that \( V_\parallel \) has a maximum when the antenna is perpendicular to \( B \) (see Figures 2a and 2b) is just what is expected for Bernstein waves since the antenna is short for their wavelengths \( (kL \approx L/P < 3) \), so that \( V_\parallel \) has a maximum when the antenna is parallel to \( k \) [Meyer-Vernet et al., 1993]. This is opposite to the modulation expected for Langmuir waves (\( k \parallel B \)) because again \( kL < 3 \) (since \( k_1L_D \ll 1 \) where \( L_D \sim 7 \) m is the Debye length), so that \( V_\parallel \) should be maximum when the antenna is parallel to \( k \parallel B \) [Meyer-Vernet, 1994]. This also explains why we do not "see" in our spectra a level increase due to Langmuir waves at the plasma frequency. Such waves contribute to the minimum thermal level, but they are damped, except at \( f_p \), whereas the Bernstein waves are undamped between the gyroharmonics. At \( f_p \), owing to the above mentioned property, Langmuir waves should be mainly detected when the antenna is close to the direction of \( B \), which does not happen on Ulysses during the studied period.

5. Comparison With the Sounder Data

The URAP experiment includes a relaxation sounder, which can detect the plasma resonance frequencies [Stone et al., 1992a]. This instrument emits a short quasi-monochromatic pulse and records the reflected signal a few milliseconds after the excitation has stopped. If the antenna geometry and orientation are adequate, a "ringing" of the plasma is expected to be observed at the frequencies where the wave group velocity in the antenna frame vanishes [see, e.g., Fejer and Yu, 1970].

This instrument was operated at the rate of one frequency sweep every 40 min near the Io torus. Before 19 hours (at 9.7 Rj), its data could not be processed, so that only few spectra were available for comparison with the radio data. The theory of the sounder has not yet been developed to give the amplitude of the resonances with the URAP antenna, which cannot be
Figure 4. Comparison between the radio and the sounder data. (top) The solid line is the average of radio measurements (dots) over a frequency step; the abrupt drop yields the maximum Doppler-shifted $f_{Q3}$, from which we deduce $f_{pc}$. (middle) Dispersion curves deduced from this value of $f_{pc}$ (for $n_h/n_e = 0.1$ or 0.25 and $T_h/T_e = 12$, 25, or 50) showing the resonances at the Doppler-shifted gyroharmonics and $f_{Q3}$ frequencies, which are roughly independent of the hot electron parameters. (bottom) Sounder spectrum and identification of these resonances (arrows), using the instantaneous values of $f_g$ deduced from the magnetometer.

Figure 5. Core electron density deduced from Bernstein wave forbidden bands along Ulysses trajectory in the outskirts of the Io plasma torus. The bottom axis shows the Jovicentric distance, and the top axis shows the distance from centrifugal equator (determined from the Goddard Space Flight Center O6 magnetic field model).

6. Summary and Final Remarks

We have shown that the plasma QTN measured by Ulysses plummets in the Bernstein forbidden bands $[f_{Qn+Ds}, (n + 1)f_g]$. As a consistency check, we have verified that the onboard relaxation sounder spectra exhibits resonances at about the same frequencies as determined nearly simultaneously from the QTN spectra. To the best of our knowledge, these forbidden bands have never been detected before, presumably because of the lack of sensitivity and frequency resolution of earlier instruments. In particular, such a detection could not be performed with the Voyager 1 spacecraft radio data from which Birmingham et al. [1981] derived the electron density in the Io plasma torus. Their method was based on detection of the upper hybrid resonance emissions which they expected to produce the strongest peaks in the power spectra (other methods used to determine the Jupiter's electron density from the plasma wave observations are summarized by Gurnett et al. [1981]). Using this method, Hoang et al. [1993] have given the electron density along the Ulysses trajectory inside 9 $R_J$, identifying $f_{UH}$ in the high band ($\sim 50$ to 1000 kHz through only 12 channels) of the URAP radio receiver in the region where $f_p > f_g$. Note that a particular relevance of all these electron density measurements is that they are unaffected by spacecraft charging or sheath effects. A further advantage of the method introduced in the present paper is that the detection of stop bands allows the location of the $f_Q$ without ambi-

Figure 4. Comparison between the radio and the sounder data. (top) The solid line is the average of radio measurements (dots) over a frequency step; the abrupt drop yields the maximum Doppler-shifted $f_{Q3}$, from which we deduce $f_{pc}$. (middle) Dispersion curves deduced from this value of $f_{pc}$ (for $n_h/n_e = 0.1$ or 0.25 and $T_h/T_e = 12$, 25, or 50) showing the resonances at the Doppler-shifted gyroharmonics and $f_{Q3}$ frequencies, which are roughly independent of the hot electron parameters. (bottom) Sounder spectrum and identification of these resonances (arrows), using the instantaneous values of $f_g$ deduced from the magnetometer, which are 1% larger for the sounder spectrum than for the radio spectrum since the latter was acquired 2 min after.

modeled as an infinitesimal dipole. Hence we shall only use the sounder data to confirm our identification of the $f_Q$ frequencies and our interpretation in terms of Bernstein waves. From the quasi-thermal noise drop (Figure 4, top), we get the Doppler-shifted $f_{Q3}$ frequency in the $f_{UH}$ harmonic band at $f_{Q3+Ds} \approx 3.57f_g \approx 44.8$ kHz, from which we deduce the cold plasma frequency $f_{pc} \approx 36$ kHz. Figure 4 (middle) shows the corresponding (Doppler-shifted) dispersion curves for several values of the hot electron parameters in the range expected at this location. We focus on the resonances at the (Doppler-shifted) frequencies $f_{Q3+Ds}$ and the gyroharmonics $f_{Qg+Ds}$ which are a direct consequence of the radio spectrum since they are roughly independent of the hot population. The peaks of the sounder spectrum (Figure 4, bottom) coincide with these resonance frequencies within 1%, except $f_{g+Ds}$, which barely emerges from the background level. This comparison uses the instantaneous values of $f_g$ deduced from the magnetometer, which are 1% larger for the sounder spectrum than for the radio spectrum since the latter was acquired 2 min after.
guity. The method of deducing \( f_{\text{TH}} \) from the strongest peak may be somewhat precarious for \( f_p \neq f_g \) when the \( f_Q \) resonance peaks at a higher level, which may happen for some antenna geometries [see, e.g., Christiansen et al., 1978, Figure 3]. In addition, \( f_{\text{TH}} \) depends on many plasma parameters, whereas the \( f_{Qn+D_s} \) are only functions of the main (cold) electron population density \( n_e \), and so their determination allows us to deduce \( n_e \). The uncertainty in \( n_e \) is about 16% and mainly due to the uncertainty in the Doppler shift produced by the plasma corotation.

Hence this method of QTN spectroscopy allows us to routinely measure in situ the core plasma density every \( \sim 2 \) min (or \( \sim 0.02 R_J \)) along that part of Ulysses trajectory between 9 and 13 \( R_J \). The results are shown in figure 5. The measurement gaps (about 20% of the spectra) are due to pollution by Jovian radio emissions (near 2030 UT) and presumably to high densities bringing the lowest \( f_{Qn+D_s} \) outside our spectral range (near 1830 UT). Let us finally recall that this determination of \( n_e \) is based on the description of the electron distribution as a superposition of two Maxwellians. There are, however, some indications that the distribution there might be, instead, kappa-like [Meyer-Vernet et al., 1995]. In such a case, the total density can still be estimated from the present analysis, since the first forbidden band can serve to localize the intraharmonic band containing \( f_{\text{TH}} \). A more accurate measurement of the electron density would require calculating the \( f_Q \) with the actual electron distribution function; this deserves further investigation.

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