X-615-69-542
PREPRINT

NASA TM X- 63804

SEQUENCE OF DIFFUSE PLASMA RESONANCES OBSERVED ON ALOUETTE II IONOGRAMS

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DECEMBER 1969

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To be submitted to J. Geophys. Res. for publication.

SEQUENCE OF DIFFUSE PLASMA RESONANCES OBSERVED ON ALOUETTE II IONOGRAMS

by

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ABSTRACT

An investigation of more than 1400 Alouette II ionograms indicates that a sequence of diffuse plasma resonances exists and that these resonances are grouped according to the following plasma conditions:

(1) f_{D1} is observed between 1.3 f_H and $2f_H$ when $2.2<f_N/f_H<3.6$,
(2) f_{D2} is observed between 2.4 f_H and $3f_H$ when $3.8<f_N/f_H<4.8$,
(3) f_{D3} is observed between 3.5 f_H and $4f_H$ when $4.5<f_N/f_H<5.8$,
(4) f_{D4} is observed between 4.5 f_H and $5f_H$ when $5.5<f_N/f_H<6.8$,

where f_{Dn} is the frequency of the diffuse plasma resonance, f_H is the electron cyclotron frequency, and f_N is the plasma frequency. When these conditions are satisfied, the corresponding f_{Dn} resonances are observed nearly 100% of the time. Diffuse resonances could not be identified when $f_N < 1.8f_H$ or when $f_N > 6.8f_H$; the upper limit may be due to insufficient frequency resolution. The diffuse resonance f_D, reported earlier by other workers as occuring at or near $1.5f_H$, corresponds to f_{D1} of this sequence. A nearly linear increase of f_{Dn} with increasing f_N/f_H is observed for n=1 and n=2 with dips near $f_N/f_H=3$ and $f_N/f_H=4$, respectively; the correlation for n higher than 3 is not as apparent. The present observations cannot be explained in terms of pure Bernstein-mode electrostatic waves.

INTRODUCTION

Nelms and Lockwood (1966) identified a diffuse resonance, which covers a relatively wide frequency range and shows somewhat similar pattern to a spread echo, in the Alouette II data. They used the notation f_D for this resonance and found the following approximate relationships: $f_D \simeq 1.5\ f_H$ and sometimes $f_D \simeq f_T/2$ or $f_D \simeq f_N/2$, depending on the local plasma conditions, where f_H is the electron gyrofrequency, f_T is the upper hybrid resonance frequency and f_N is the electron plasma frequency. Under certain plasma conditions, no simple relationship could be identified between f_D and the other principal resonances (see Calvert and McAfee (1969) for a review of these resonances); no explanation or hypothesis was presented for the observational results.

The purpose of the present paper is to report that a sequence of diffuse resonances (which includes the f_D resonance mentioned above) is observed on the Alouette II ionograms, and to show that all of these resonances are related in a definite manner to local plasma conditions. The work is based on an analysis of Alouette II data selected from the first 7 months of its life time. The time interval was separated into three periods in order to obtain a suitable variation of the plasma parameter f_N/f_H at three telemetry stations chosen to cover the latitude range from -50°S to 65°N.

OBSERVED DATA

The present study was based upon Alouette II data corresponding to an altitude range of 500 km to 3000 km, to a latitude range of -50°S to 65°N (near 1000 km altitude), and to two seasons (summer and spring). This coverage was obtained by using the data from the following three telemetry stations: (1) Santiago (November 29, 1965 to March 7, 1966), (2) Ottawa (April 5, 1966 to Arpil 26, 1966), and (3) Quito (April 17, 1966 to June 19, 1966).

In Figures 1 (a) – (d), examples of plasma resonances are indicated on the conventional Alouette II ionogram format (Nelms et. al., 1966). The signals of interest are labelled f_{D1}, f_{D2}, f_{D3} and f_{D4}; the subscript 1 to 4 indicates that each resonance exists between the cyclotron harmonics nf_H and $(n+1)f_H$, where $n = 1$ to 4. The diffuse plasma resonance f_{D1} (Figure 1a) corresponds to f_D which was initially investigated by Nelms and Lockwood (1966). The frequency and time duration of this resonance strongly depends on the plasma parameter f_N/f_H. The pattern of the f_{D1} resonance in Figure 1a is typical for the case when $f_{D1}/f_H = 1.7$. Under these conditions the resonant time duration is considerably less than for the condition $f_{D1}/f_H \simeq 1.5$ where the duration time is usually from 10 to 20 msec. The f_{D2} resonance (Figure 1b) has a pattern similar to that of f_{D1} in that it also has a frequency spectrum broader than the typical spectra of the principal plasma resonances. The f_{D3} resonance shown in Figure 1c suggests a double peak structure; the f_{D2} resonance appears on the same ionogram. An example of f_{D4} is given in Figure 1d. For higher values of n, the diffuse resonances are usually at frequencies greater than 2.0 MHz, where the frequency resolution is poorer. Also for higher values of n the spectrum tends to broader.

The f_{Dn} resonances are called diffuse resonances in view of their broad frequency spectrum and as stated earlier they occur between nf_H and $(n+1)f_H$. This definition of f_{Dn} does not include the wide band signals which are seen below the gyro-frequency (Barry, et. al., 1967), and it does not include the broad responses frequently observed near the local Z-mode frequency. The plasma resonances which are observed at frequencies between nf_H and $(n+1)f_H$ but occur above the upper hybrid resonance frequency (Warren and Hagg, 1968) are also excluded from this definition.

From a total of 147 satellite passes observed during the above mentioned time intervals, 1477 ionograms were examined for the presence of f_{Dn} diffuse resonances. On about 900 of these ionograms $f_N/f_H < 1.8$ and no f_{Dn} resonance was observed. On the remaining ionograms, where $f_N/f_H > 1.8$, f_{Dn} diffuse resonances were nearly always observed.

The scaled frequency of each of these diffuse resonances was taken as the center frequency of the diffuse resonance pattern except for very asymmetrical resonances; in this case, the frequency of the maximum duration portion of the resonance was measured. The plasma parameter f_N/f_H was obtained by scaling the frequencies of the resonances observed at f_N and f_H on each ionogram. On a few ionograms, however, where the frequencies of the f_N or f_H resonance could not be obtained directly, f_H was determined from the 2 f_H or 3 f_H resonance and f_N was determined from the observed cut-off value f_X of the extraordinary wave reflection trace.

A SEQUENCE OF DIFFUSE RESONANCES f_{Dn}

The f_{Dn} resonances observed on the Quito data are presented in Figure 2, where f_{Dn}/f_H is plotted versus f_N/f_H. This presentation reveals a sequence of f_{Dn} resonances which consists of four groups defined by the conditions $n < f_{Dn}/f_H < (n+1)$ for $n = 1$ to 4, with clear gaps of distribution between each group. Similar resonances corresponding to $n \geq 5$ could not be definitely identified, but this result is attributed to observational difficulties. Sometimes, the f_{Dn} resonances are accompanied by subsidiary resonances in each group. These resonant frequencies, which are plotted as open circles and x's in Figures 2 and 3, form different branches which are separated from the main branch (plotted as solid points). Nelms and Lockwood (1966) also reported the occasional occurrence of subsidiary resonances associated with their f_D resonance. Two subsidiary branches are observed with f_{D1}, one on the high frequency side of the main branch and one on the low frequency side. These subsidiary branches are not seen simultaneously, and they do not occur over the full range of f_N/f_H values for which the main f_{D1} resonance is observed. Only one subsidiary branch is observed with f_{D2} and it is on the high frequency side of the main branch. Again, the subsidiary branch does not extend over the full range of f_N/f_H values for which the main branch is observed. The rate of occurence is higher for f_{D2} than that is for f_{D1}. Also, the subsidiary resonances belonging to f_{D2} have a more irregular pattern than those belonging to f_{D1} and sometimes it becomes difficult to discriminate them from the main branch resonance. This difficulty of discrimination tends to increase with increasing n (see for example f_{D3} in Figure 1c).

Detailed results of the f_{D1} and f_{D2} resonance scaling for the combined Quito and Santiago data are shown in Figure 3. When $f_N/f_H < 1.8$ there is no f_{D1} resonance. The conditions $1.8 < f_N/f_H < 2.2$ and $3.6 < f_N/f_H < 3.8$ define transition regions where the f_{D1} and f_{D2} resonances, respectively, are not constantly observed. In the range $2.2 < f_N/f_H < 3.6$ and $3.8 < f_N/f_H < 4.8$, f_{D1} and f_{D2}, respectively, are observed almost 100% of the time independently of the satellite altitude, latitude, local time, and the season. The main branch resonance shows a functional relationship with f_N/f_H; the quantity f_{Dn}/f_H varies almost linearly with f_N/f_H. There is however, a clear dip around $f_N/f_H = 3$ for f_{D1}, and an indication of a dip around $f_N/f_H = 4$, for f_{D2}. The plasma conditions under which the f_{D3} and f_{D4} resonances (Figure 2) can be observed nearly 100% are the following: $4.5 < f_N/f_H < 5.8$ for f_{D3}, and $5.5 < f_N/f_H < 6.8$ for f_{D4}. A correlation between f_{Dn}/f_H and f_N/f_H is not apparent for these two groups.

Although the study of Ottawa data was limited to about 70 ionograms, nearly all of these exhibited f_{D1} resonances clearly split into a double peak structure. These separate peaks, as observed on the Ottawa data, are plotted as open squares and solid dots in Figure 4. There is a remarkable agreement between the average location of the f_{D1} main resonance from the Santiago and Quito data and the midpoint between the separate peaks of the Ottawa data. This frequency splitting of f_{D1} is independent of f_N/f_H, and appears to be dependent on the satellite latitude.

DISCUSSIONS

The f_{Qn} resonances observed at frequencies between the electron cyclotron harmonic values can be explained as the result of electrostatic plasma waves, propagating perpendicular to the magnetic field (the so-called Bernstein-mode waves), which are initiated by the transmitted sounder pulse (Warren and Hagg, 1968). The occurence of the f_{Dn} resonance in groups corresponding to $n < f_{Dn}/f_H < (n+1)$ with clear gaps between each group, and the dependency of f_{Dn} on f_N/f_H, suggests a similarity between the f_{Dn} and f_{Qn} resonances. The f_{Dn} resonances, however, differ from the f_{Qn} resonances in that the f_{Qn} resonances are observed only when $f_{Qn} > f_T$ (Warren and Hagg, 1968), whereas the f_{Dn} resonances are observed only when $f_zS > f_{Dn}$, (see Figure 2), which implies $f_T > f_{Dn}$ since $f_T > f_zS$, where f_T is the upper hybrid resonance frequency and f_zS is the Z-mode frequency at the satellite level.

From the theoretical point of view, there is a clear difference between the f_{Dn} and f_{Qn} resonances in that the dispersion curves of the exact Bernstein-mode waves do not indicate a region of zero group velocity corresponding to the f_{Dn} resonances, whereas they do for the f_{Qn} resonances. Thus, if the f_{Dn} resonances are to be attributed to plasma waves of low group velocity, which remain in the vicinity of the satellite, then plasma waves other than the pure Bernstein-mode waves must be involved.

SUMMARY

The results of the present data analysis of the f_{Dn} diffuse resonances observed by Alouette II are the following:

1. A sequence of diffuse plasma resonances f_{Dn} which consists of several groups of corresponding n, is observed. Each group covers a relatively wide frequence range, and the individual groups are clearly separated from each other in frequency.

2. Sometimes, the f_{Dn} resonances are accompanied by subsidiary resonances which lead to additional branches separated from the main f_{Dn} branch on the f_{Dn}/f_H versus f_N/f_H diagram. Two subsidiary resonances, corresponding to a given n value, are never observed simultaneously, and the subsidiary resonances occur less frequently than the main branch resonances. There are two subsidiary branches in the f_{D1} group, one on the high frequency side and the other on the low frequency side of the main branch. In the f_{D2} group, there is only one subsidiary branch which is on the high frequency side of the main branch.

3. Occasionally, the main f_{D1} resonance is split into two peaks. This splitting appears to be related to latitude rather than to f_N/f_H.

4. In the f_{D1} and f_{D2} groups, f_{Dn}/f_H increases almost linearly with f_N/f_H with an indication of dips near $f_N/f_H = 3$ for f_{D1}, and near $f_N/f_H = 4$ for f_{D2}.

ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks to Dr. R. F. Benson for suggesting the investigation of the diffuse resonance problem and for his stimulating discussions during this study. The author is also grateful for helpful discussions witn Mr. J. E. Jackson and Dr. S. J. Bauer.

REFERENCES

Barry, J.D., P. J. Coleman, and W.F. Libby, Radio Reflection by Free Radicals in Earth's Atmosphere, Science, 156, 1730, 1967.

Calvert, W., and J.R. McAfee, Topside-Sounder Resonances, Proc. IEEE, 57, 1089, 1969.

Nelms, G.L. and G.E.K. Lockwood, [illegible]esults from the topside sounder in the Alouette II sat[illegible]te, Space Res., 7, 604, 1966.

Nelms, G.L., R.E. Barrington, J.S. Belrose, T.R. Hartz, I.B. McDiormid and L.H. Brace, The Alouette II satellite, Can. J. Phys., 44, 1419, 1966.

Warren, E.S. and E.L. Hagg, Observation of electrostatic resonances of the ionospheric plasma, Nature, 220, 466, 1968.

FIGURE CAPTIONS

Fig 1. Ionograms illustrating diffuse plasma resonances: (a) f_{D1} resonance observed at Quito on April 22, 20:40:16 UT, 1966 (1007 km, 7.0° S geographic latitude, 4.68° N dipole latitude; $f_N/f_H = 3.17$), (b) f_{D2} resonance observed at Santiago on January 28, 18:44:50 UT, 1966 (517 km, 37.91°S geographic latitude, 36.16°S dipole latitude; $f_N/f_H = 4.01$), (c) f_{D3} resonance observed at Quito on May 26, 17:57:37 UT, 1966 (606 km, 20.09°N geographic latitude, 31.38°N dipole latitude; $f_N/f_H = 5.21$), (d) f_{D4} resonance observed at Quito on May 26, 17:57:05 UT, 1966 (590 km, 17.99°N geographic latitude, 29.27°N dipole latitude; $f_N/f_H = 6.21$).

Fig. 2. Scaling results of the f_{Dn} resonances for the Quito data. Open circles and x's indicate resonances subsidiary to the main resonance (solid points). The histogram at the top of the figure indicates the number of ionograms scaled vs. f_N/f_H. The normalized local Z - mode frequency f_Z/f_H is also indicated.

Fig. 3. Scaled f_{D1} and f_{D2} resonance frequencies vs. f_N/f_H as observed on the Quito and Santiago data (the Quito data of Fig. 2 are included in this figure). See caption with Fig. 2.

Fig. 4. The scaled f_{D1} resonance frequency vs. f_N/f_H for the Ottawa data. The open squares and solid points represent the two peaks observed on the main resonances; the x's represent subsidiary resonances. The three island-like figures represent the boundary of the f_{D1} data points from Quito and Santiago as plotted in Fig. 3. A histogram showing the number of ionograms scaled vs. f_N/f_H is given at the top of the figure.

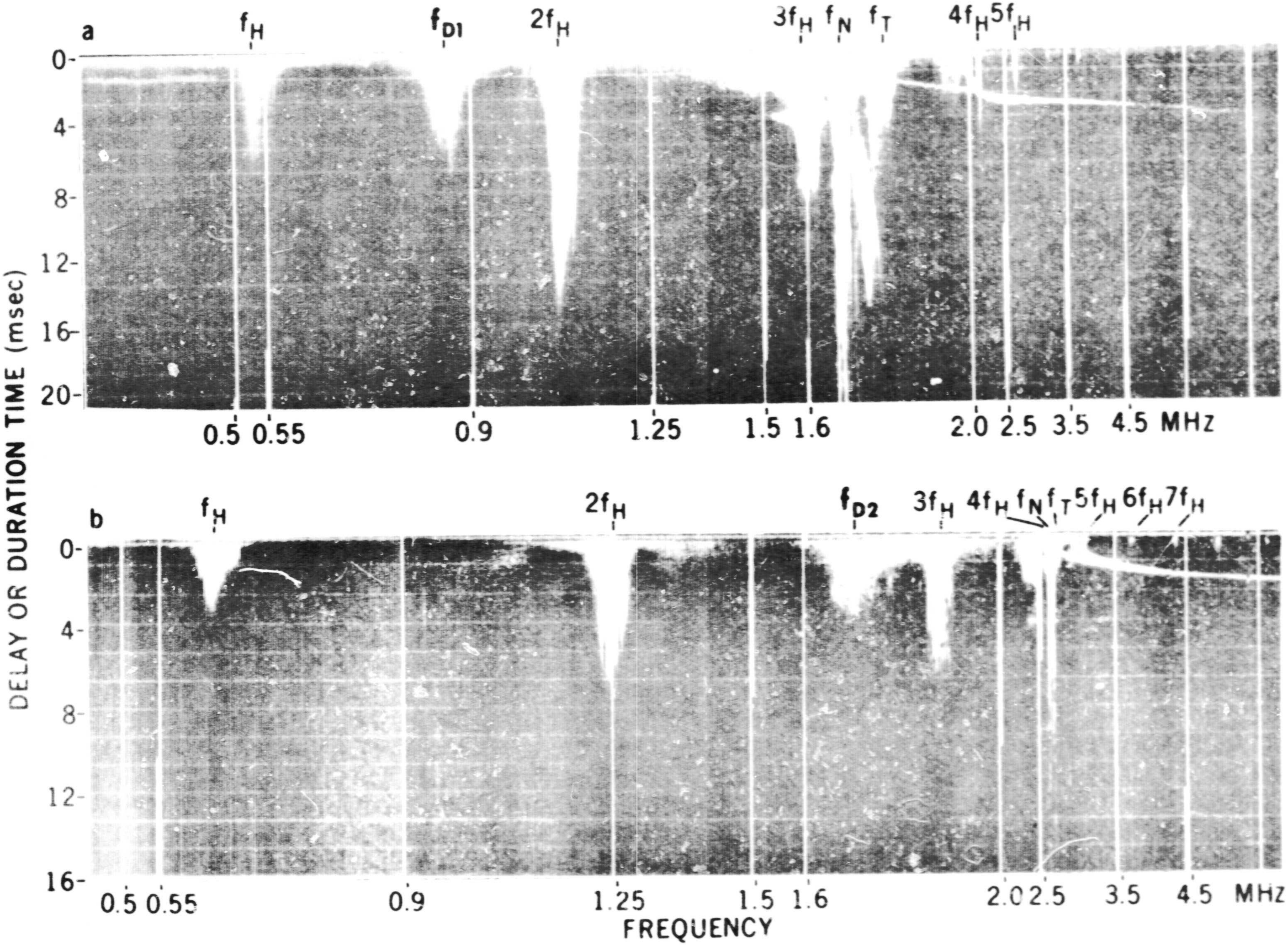


Figure 1

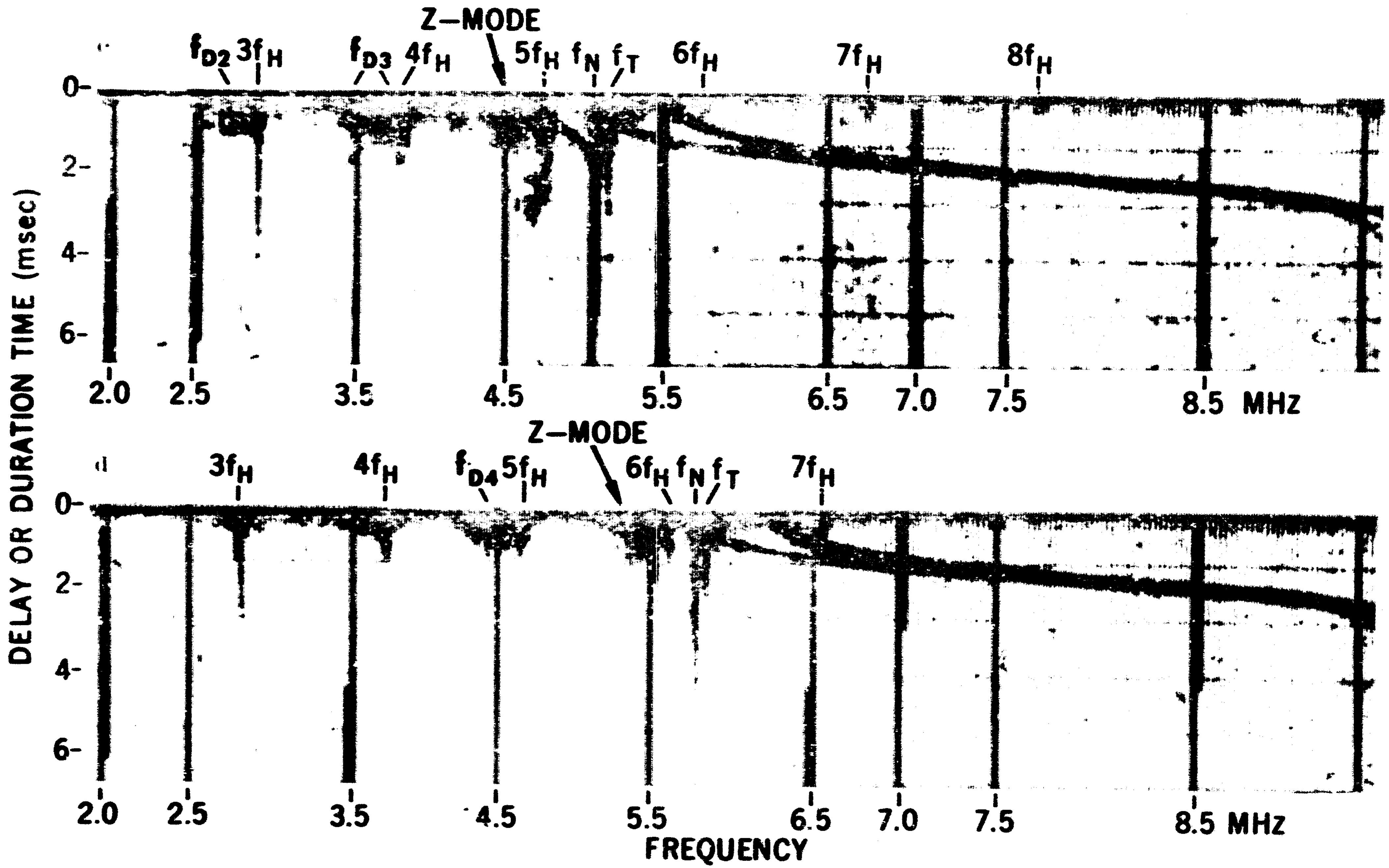

Z—MODE
f_{D2} $3f_H$ f_{D3} $4f_H$ $5f_H$ f_N f_T $6f_H$ $7f_H$ $8f_H$
0- 2- 4- 6-
2.0 2.5 3.5 4.5 5.5 6.5 7.0 7.5 8.5 MHz
Z—MODE
$3f_H$ $4f_H$ f_{D4} $5f_H$ $6f_H$ f_N f_T $7f_H$
0- 2- 4- 6-
2.0 2.5 3.5 4.5 5.5 6.5 7.0 7.5 8.5 MHz
DELAY OR DURATION TIME (msec)
FREQUENCY

Figure 1A

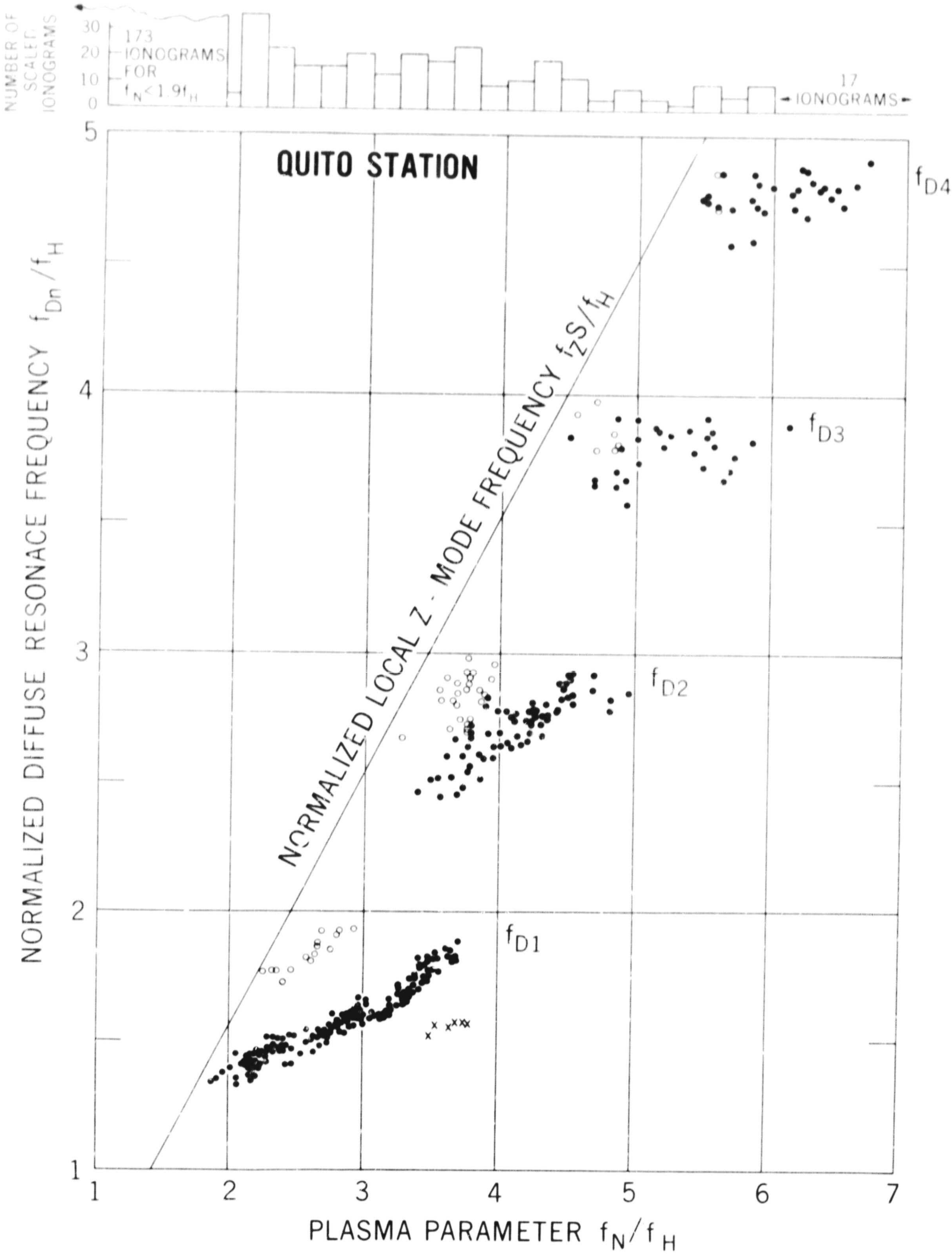
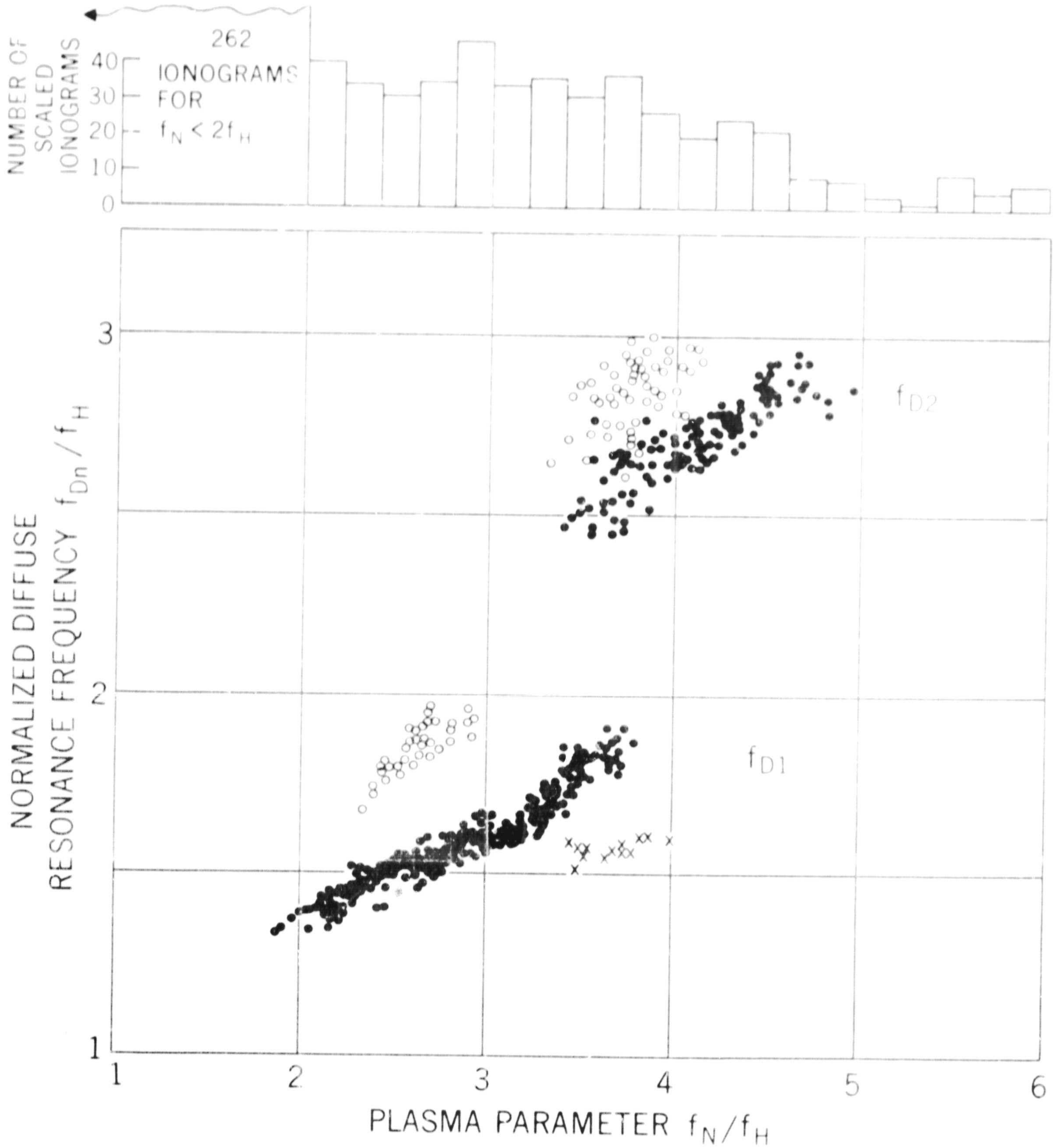

NUMBER OF SCALED IONOGRAMS
173 IONOGRAMS FOR $f_N < 1.9 f_H$
17 IONOGRAMS
QUITO STATION
NORMALIZED DIFFUSE RESONACE FREQUENCY f_{Dn}/f_H
NORMALIZED LOCAL Z - MODE FREQUENCY f_{ZS}/f_H
f_{D1}
f_{D2}
f_{D3}
f_{D4}
PLASMA PARAMETER f_N/f_H

Figure 2



262
IONOGRAMS
FOR
$f_N < 2f_H$
NUMBER OF SCALED IONOGRAMS
40
30
20
10
0
NORMALIZED DIFFUSE RESONANCE FREQUENCY f_{Dn}/f_H
3
2
1
f_{D2}
f_{D1}
1
2
3
4
5
6
PLASMA PARAMETER f_N/f_H

Figure 3

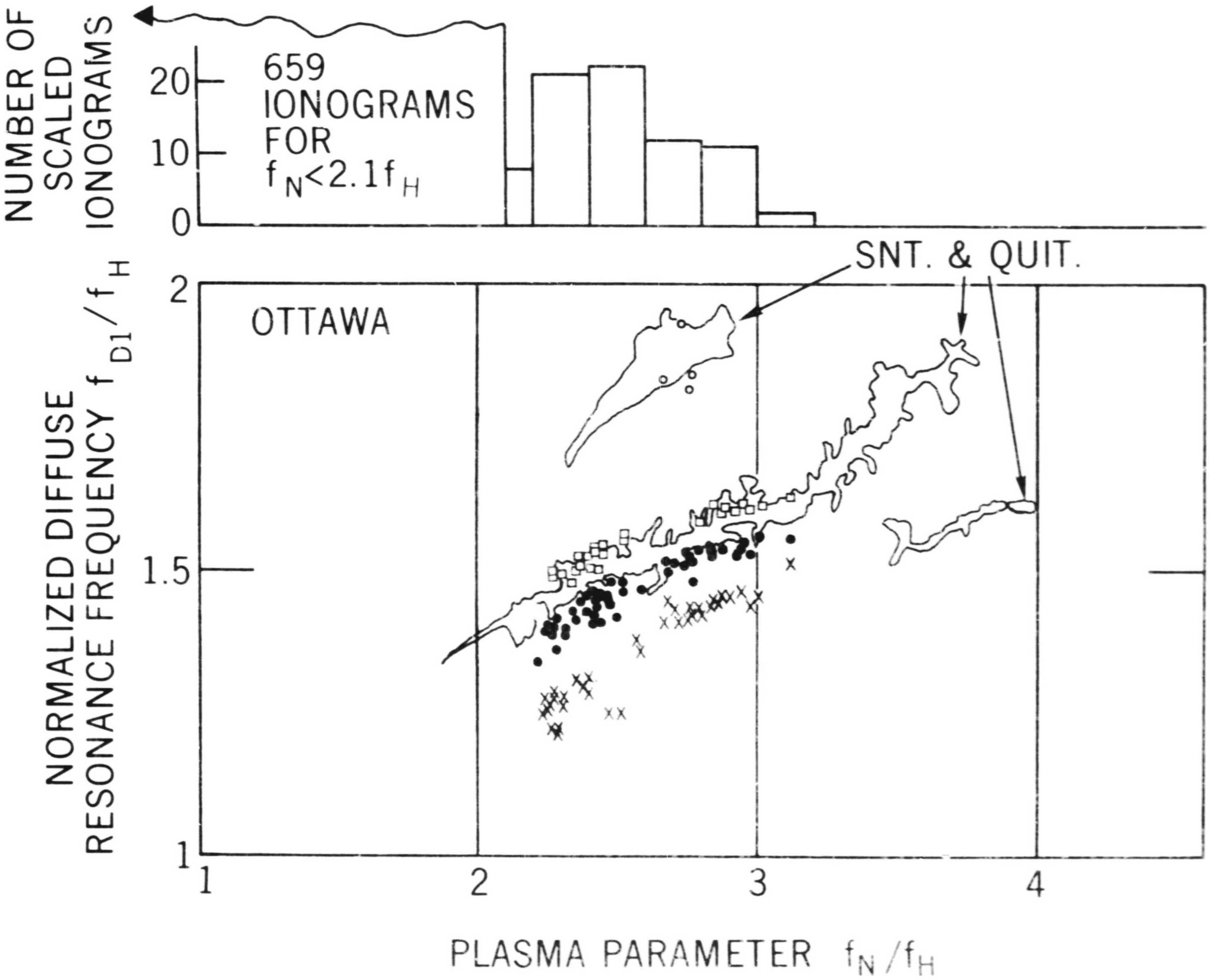

NUMBER OF SCALED IONOGRAMS
20
10
0
659 IONOGRAMS FOR $f_N < 2.1 f_H$
SNT. & QUIT.
OTTAWA
NORMALIZED DIFFUSE RESONANCE FREQUENCY f_{D1}/f_H
2
1.5
1
2
3
4
PLASMA PARAMETER f_N/f_H

Figure 4