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Spectral characteristics of ULF waves observed simultaneously in space and on ground stations

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ABSTRACT

Ultra low frequency waves with periods between a few tens of minutes to a few minutes fall within the range of Ps-6 and Pc-5 micropulsation and are observed as fluctuations in the magnetic fields in space as well as at the ground magnetic observatories. In this paper we have analysed magnetic data recorded by satellites outside the magnetosphere (IMPSatellite), inside the magnetosphere (GOES- satellite) and at three ground stations. The objective is to investigate how the waves generated in the interplanetary space get modified when they travel through magnetosphere to the ground. We have noticed that the low frequency part of the spectrum of the ULF waves propagate to the surface of the earth with very little attenuation which indicates direct propagation as fast mode Alfven waves. However, the waves with higher frequencies (> 1mHz.) which are present in the IMP data, seem to propagate inside the magnetosphere as cavity modes. The frequencies of these waves can be explained in terms of over reflection at the magnetopause boundary as suggested by Mann et. al. (1999).

INTRODUCTION

The Ultra low frequency hydromagnetic waves, called geomagnetic micropulsations, detected on the ground, are generated in the magnetosphere and in the interplanetary space. These waves carry information's about the various properties of the plasma at the region of generation. As these waves propagate through the near-earth space, their characteristics undergo substantial change induced by the propagation medium. Thus the study of the micro pulsations on the ground as well as in space provides information's about the near earth plasma environment.

A host of mechanisms are responsible for the generation of these waves. Mostly they are created inside the magnetosphere by various plasma instabilities. The magnetosphere also responds to the short period change of the solar wind pressure, or plasma oscillations at the bow shock region, by exciting some discrete eigen- frequencies of cavity modes or wave guide modes (Walker 1998; Wright 1994) of the magnetosphere as a whole. The magnetopause boundary also may sustain surface waves, which may propagate to the interior of the magnetosphere. Generally the frequency of the waves as well as the propagation properties is controlled by the exact nature of the medium and the particular mechanism of production of the waves.

The observed ULF waves on the ground and inside the magnetosphere are explained, primarily, in terms of these above-mentioned mechanisms. In this article we shall study the quasi-periodic low frequency waves, which are seen in the interplanetary space as well as on the ground.

Our data set will be IMP satellite magnetic field data, Magnetometer data on the ground stations of low and mid latitudes, and at the Geo-synchronous location of 6.6 Re inside the magnetosphere. Thus we should be able to trace the waves as they propagate from the distant space through the magnetosphere, and to the ground. The purpose is to explain these coordinated ground and space observations in terms of the possible propagation mechanisms.

DATA

We have chosen a few days when wave activities were observed both on the ground and at distant space. The low Ap values of these days ensure that complicated solar wind disturbances are ruled out. These are October 19, December 4, and December 10,1991 respectively.

The IMP satellite was at the Up stream interplanetary space, possibly beyond the bow shock area. The average location of the IMP in the, X-Y (GSE-coordinate system) plane, is shown in Fig.1a. The hourly values of the solar wind velocities are shown in Fig. 1b for these days. During these periods, the Geo-synchronous satellite, GOES-6 was located at approximately between 135 to 136 degree longitude zones. In addition, we have chosen three ground stations at the following locations: (i) ALIBAG (ABG): Dipole latitude of +9.7° N and Geographic Longitude of 78° E, (ii) TRIVANDRUM (TRD): Dipole latitude - 0.8° S and Geographic Longitude of 76.8 degree E and (iii) ADELAIDE (ADL): Dipole latitude of -46.46° S and the Geographic longitude of 138.4°.

Thus, the GOES-6 was almost at the same longitude of ADL. Similarly TRD is an Equatorial electrojet station where as ABG is an Off-equatorial station at the same longitude zone as TRD.

The data sets consist of the horizontal components of the magnetic fields for the ground stations, three components of the magnetic fields at GOES satellite and the three components of the magnetic fields at IMP satellite. The data intervals are one minute for the ground stations and the GOES, where as it is 1.024 minutes for the IMP data. Thus we have data from low

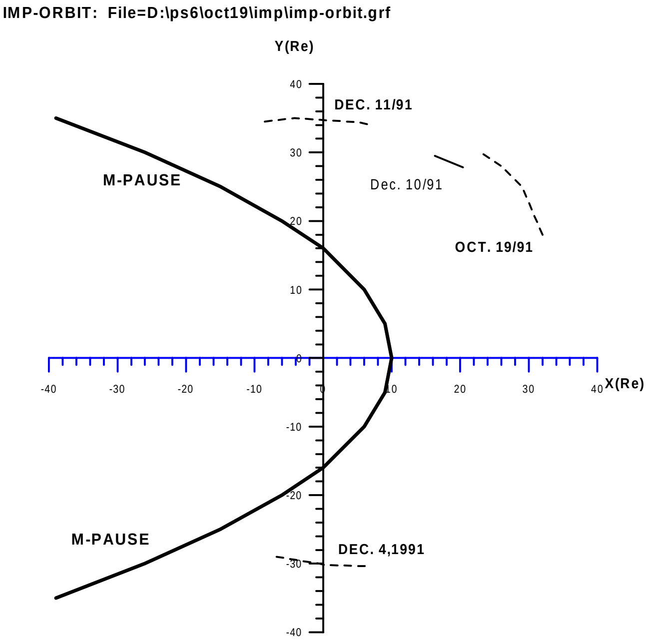

Figure 1a. The approximate locations of the IMP-satellite in the X-Y plane (GSE- co-ordinates) during the periods of this investigation. The solid line represents the presumed magnetopause boundary which may not be in scale.

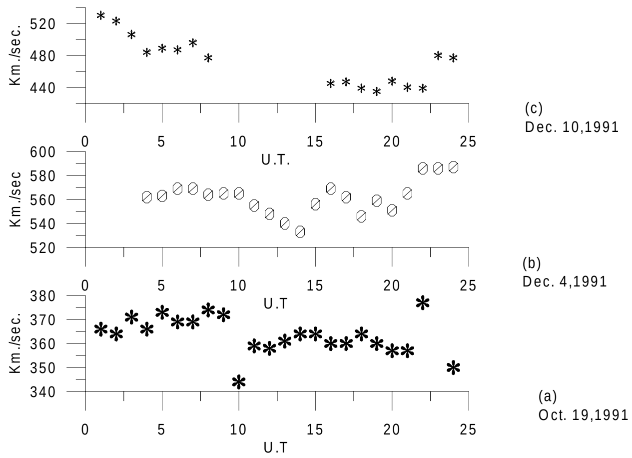

Figure 1b. The hourly values of the solar wind velocity (Km./ sec.) for the days indicated in the figures.

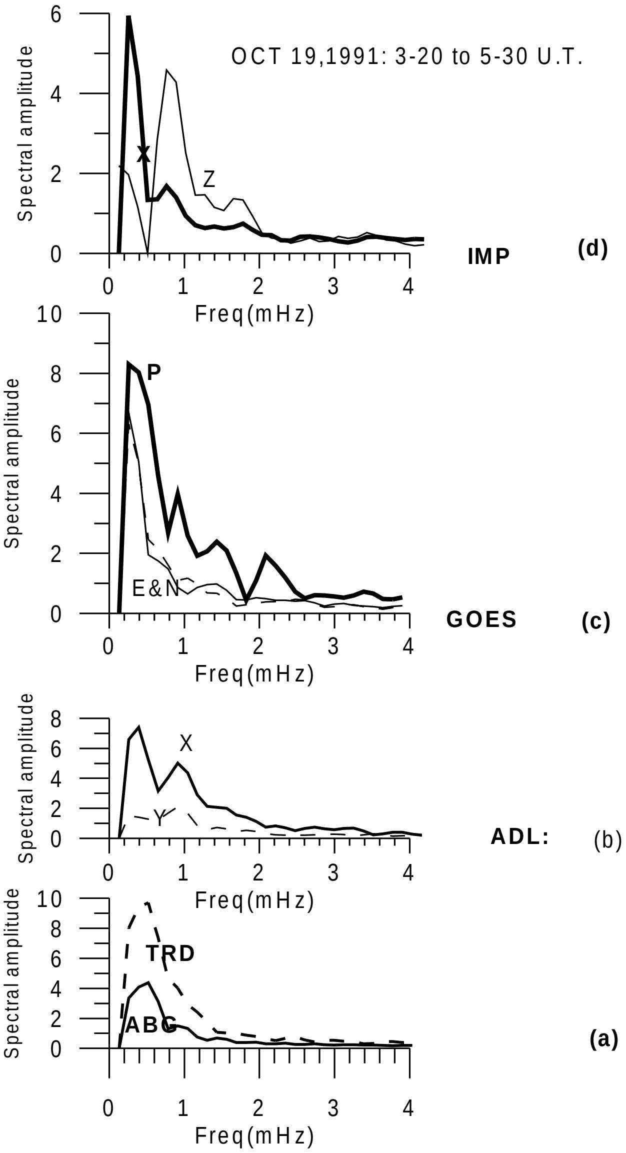

Figure 2 (a-d). The spectral amplitudes of the various components of the magnetic fields on October 19, 1991 during the period from 03-30 U.T. to 05-30 U.T. (a) for ALB (solid line) & TRV(dashed line), (b) for the station ADL (H-component= solid line; D-component = dashed line respectively), (c) for the GOES-6 (P= thick solid line, E=dashed line, N=thin solid line respectively) and (d) for the IMP-data (X= thick solid line, Y= dashed line and Z=thin solid line respectively)

and mid latitude ground stations, in the magnetosphere at about 6.6 Re (GOES-6) and at the interplanetary medium (at IMP) beyond the earth's magnetosphere cavity.

On all these days wave activities with Ultra Low Frequencies, periods ranging from a few minutes to a few tens of minutes, were observed at all the locations mentioned above, almost through out the days. Since large distances of several Re separate all the observations points, it is natural to assume that these are global disturbances generated out side the terrestrial environment, but propagated to the interior of the magnetosphere by some mechanism.

All the data sets were first treated by a low pass numerical

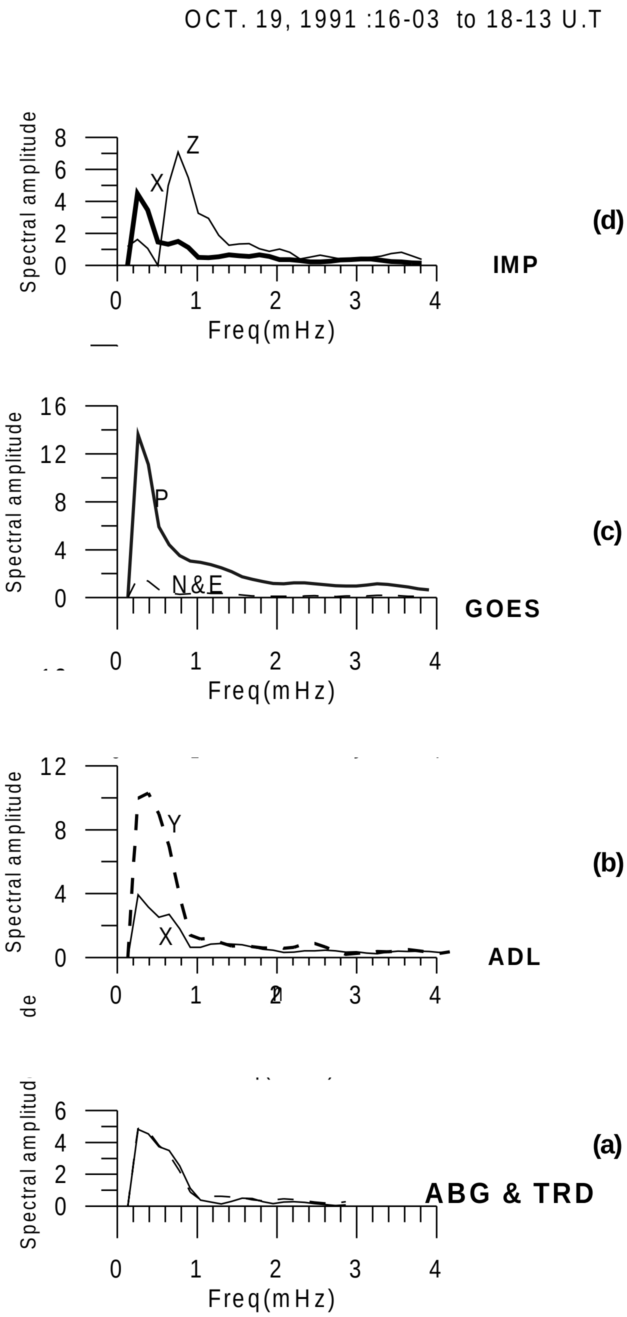

Figure 3 (a-d). Same as Fig.2, : from 16-03 to 18-13 U.T.

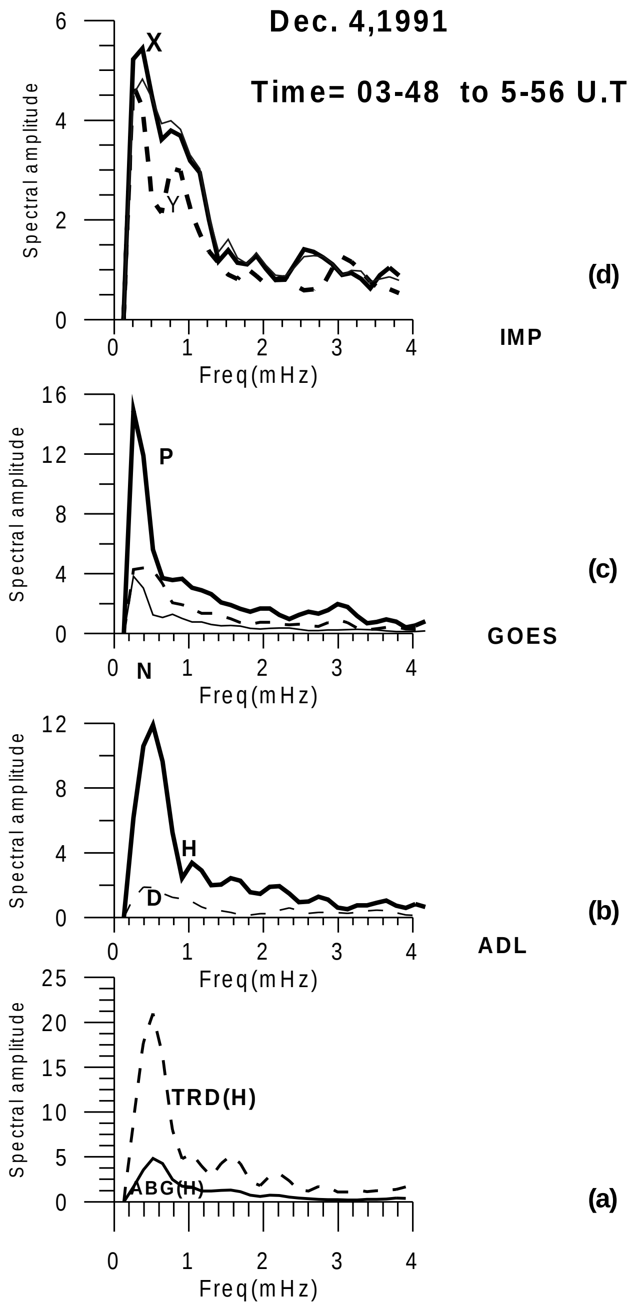

Figure 4 (a-d). same as Fig.2 , for December 4, 1991 from 03-48 to 05-56 U.T.

filter to eliminate the very low frequency trends with periods of 256 minutes and lower. After de-trending these data sets, we have subjected them to the Fast Fourier Transform (FFT) analysis to get power spectra of the respective components. The power is the square of the FFT amplitude. However, we have plotted the amplitudes, rather than the power. Some sample frequency spectra are shown in Figs 2(a-d) and 3(a-d), during two periods (one in the morning and another in the after noon) on October 19,1991. Similar spectra are shown in Figs 4(a-d) for December 4,1991. The results for December 10,1991 are shown in Figs 5 respectively. The various components are explained in the figure captions.

For ABG & TRD we have plotted the spectra for the horizontal component H, whereas for ADL we have plotted both the Horizontal component (H) and the D-component respectively. In the case of the GOES-6, the P-components are

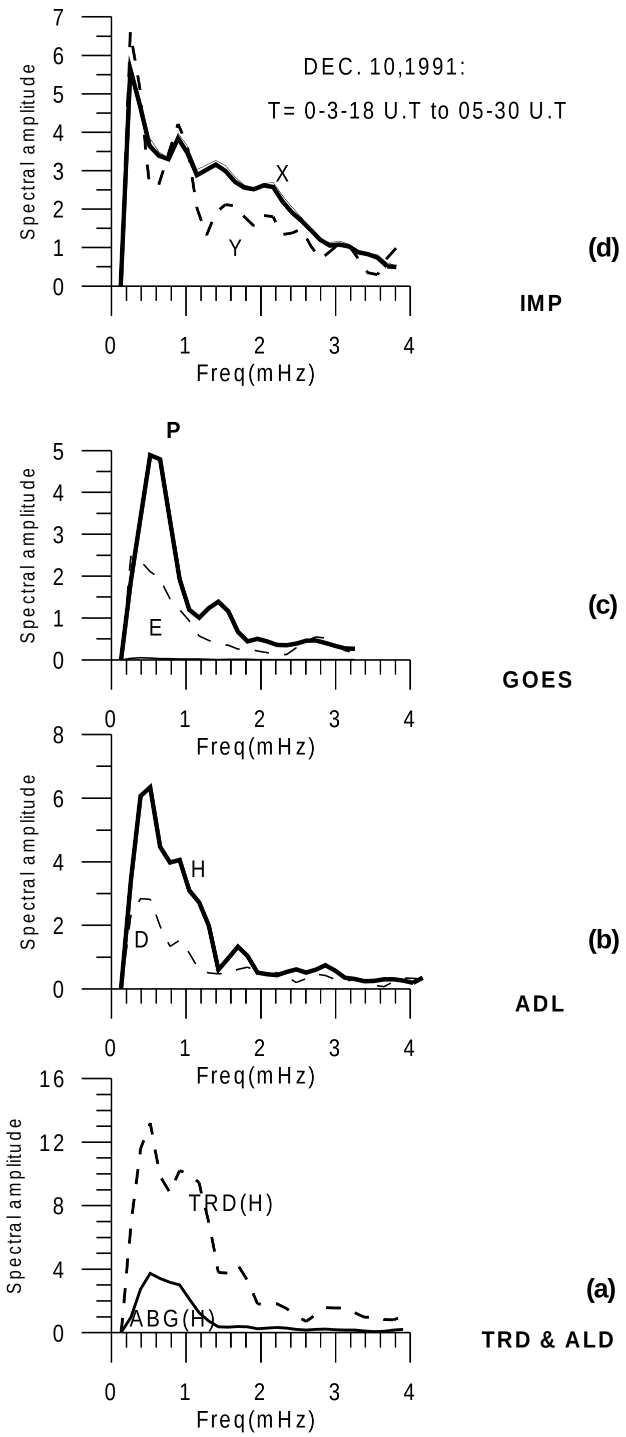

Figure 5 (a-d). Same as Fig. 2: for December 10, 1991 : from 03-18 to –5-30 U.T.

parallel to the spin axis, E-component is radically towards the earth, and the N-component is the third orthogonal direction. For the IMP data, X, Y and Z are in GSM co ordinate system.

RESULTS AND DISCUSSIONS

The general characteristics of all the spectra are that there are basically two groups of discrete frequencies present in all the cases. The low frequency band below 1.0 MHz, present in the IMP-data, is also present in the spectra of the magnetic fields at the ground stations, both at the low (ABG & TRD) and at the mid-latitude (ADL) regions. This band of the spectra in the IMP-data is almost always transmitted to the ground through the GOES-location. An other set of discrete frequencies present in the IMP-data has frequencies above 1.0mHz, some times as high as 3.0 MHz. This group shows complicated characteristics both with respect to the location of the stations and the individual event. Now we shall discuss them event wise. However, before this discussion, let us review the possible modes of propagation of these signals. It is natural to assume that the sources of these waves are in the interplanetary medium. These are propagating towards the earth as fast magneto- sonic waves, which may travel in any direction with respect to the ambient magnetic field. If some frequency matches with any of the Eigen modes of the magnetospheric cavity, that particular mode will be globally detected inside the magnetosphere and on the ground. This cavity is bounded by the magnetopause surface as the outer boundary, and some inner region of the magnetosphere, possibly the ionosphere or the surface of the solid earth. This cavity has some distinct set of natural frequencies of its own, which are excited when it is subjected to external disturbances. Only the frequencies matching these Eigen modes of the cavity are trapped inside the magnetosphere. Therefore, the cavity functions, somewhat like a filter, which transmits some frequencies preferentially towards the earth. Statistically, it was observed that these frequencies are around, 1.3, 1.9, 2.7, 3.3 kHz (Samson et al. 1991; Walker et al. 1992; Ruohoniemi et al. 1991). Theoretical calculations (Walker 1998) also endorse these observations. Kelvin–Helmohltz Instability (KHI) at the magnetopause, although a surface phenomenon, can also excite cavity modes, if the solar wind velocity is very large (3-4 times the Alfven velocity), as suggested by Fujita, Glassmeier & Kamide (1996). These waves are in the frequency range of 3.0 MHz and above. On the other hand Mann et al. (1999) proposed that over reflection from the magnetopause boundary might excite wave-guide or cavity modes, which may have somewhat, lower frequencies depending on the solar wind velocity. While solar wind is the main source of wave energy in the KHI mechanism, it is not so for the over reflection model of Mann et al. (1999). In the latter case, the wave must be in the external medium itself. For the ordinary cavity modes, the frequencies are basically determined by the size of the cavity. On the other hand the over reflection model tells us that the cavity size as well as the solar wind velocity control the eigen frequency and the trapping efficiency of the wave inside the magnetosphere.

On the basis of the above known theories, we shall discuss the present observations. October19, 1991 was a quiet day with low Ap value of 13. As seen from Fig.1a, IMP satellite was positioned at a distance of about 30 R_e from the earth, basically at the early after noon sector. From Fig.2d, it is evident that three discrete frequencies are present in these spectra; these are 0.3 MHz, 0.9 MHz, and 1.7 MHz respectively. The lowest frequency of 0.3 kHz signal, present only in the X-component, is transmitted with very little attenuation to the interior of the magnetosphere and then on the ground as evident from Figs (2a-c). Such low frequency cannot be any eigen-mode of the magnetospheric system. Therefore, this must be a direct propagation in space from the interplanetary region to the ground. Since magnetic field is not in the direction of the propagation the most likely mode is the fast Alfven wave. The higher frequencies, 0.9 MHz and 1.7 MHz, present in the Z-component at IMP, are also present both at GOES location as well as at the mid-latitude ground station of ADL. However, the low latitude stations TRD & ABG do not show any signature at these frequencies. It is unlikely that direct transmission is a possible mode of transmission for these high frequency signals. Kelvin-Helmholtz (KH) wave at the magnetopause surface also can be ruled out, although the solar wind velocity at this hour was moderately high ~ 400 Km./sec. Moreover, it is very difficult for any surface wave to travel very deep inside the magnetosphere and on the ground with such small attenuation. Therefore, the mode of propagation should be some kind of global cavity oscillation or wave-guide type propagation. However, the magnitude of the frequencies seems to be rather low compared to the possible wave-guide or cavity modes (which are closer to 2mHz and above). But the mechanism of over reflection proposed by Mann et al. (1999) can excite trapped cavity modes with somewhat lower frequencies, if the solar wind speed is correct. Another feature of this mechanism is that, the trapping efficiency of the cavity is less if the solar wind velocity is small. The Fig.3 (a-d), representing the spectral distributions on the same day of October 19,1991 during the period of 16-03 to 18-13 U.T., shows that the frequency of 0.8 mHz line in the IMP data is not visible inside the magnetosphere, although the lower frequency line of 0.3 mHz is present globally. At this time of the day, the solar wind speed was rather small, about 340 Km./sec. Therefore, the trapping power of the cavity is expected to be weak.

Similarly, the spectra during the morning hour on December 4,1991, are shown in Fig.4 (a-d). IMP satellite was located at the morning sector during this day. The solar wind velocity was quite high, of the order of 550 Km./sec. All the three components of the magnetic field show similar spectral structure in the IMP-data set. The high as well as the low frequency lines are globally transmitted to GOES locations as well as on the ground stations. It is interesting to note, that on this day of high solar wind velocity, the spectral line with frequency near 3 MHz is also efficiently trapped inside the magnetopause-ground cavity. We have also presented similar spectra for December 10, 1991 in Fig.5. On the morning hours on this day, the solar wind velocity was rather high, about 500 Km. / sec. The Z-component of the IMP-data did not show any discrete structure. But the X- and Y- components exhibit rather similar spectral pattern. These lines are also globally transmitted to the interior of the magnetosphere as well as on the ground.

Even the low latitude station at TRD received these signals of IMP. It is interesting to note that the high frequency branches of the IMP spectrum have rather wide spectral widths compared to those at the GOES spectrum or the spectra at the ground locations. This indicates some filtering process, presumably by the magnetosphere cavity. Since the solar wind velocity was high, the over reflection mechanism may be a good candidate as a transmission mechanism.

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