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MICROSTRUCTURE OF THE IMF TURBULENCES AT 2.5 AU

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ABSTRACT

A detailed analysis of small period (15-900 sec) magnetohydrodynamic (MHD) turbulences of the interplanetary magnetic field (IMF) has been made using Pioneer-11 high time resolution data (0.75 sec) inside a Corotating Interaction Region (CIR) at a heliocentric distance of 2.5 AU in 1973. The metods used are the hodogram analysis, the minimum variance matrix analysis and the coherence analysis. The minimum variance analysis gives evidence of linear polarized wave modes. Coherence analysis has shown that the field fluctuations are dominated by the magnetosonic fast modes with periods 15 sec to 15 min. However, it is also shown that some small amplitude Alfven waves are present in the trailing edge of this region with characteristic periods (15-200 sec). The observed wave modes are locally generated and possibly attributed to the scattering of Alfven waves energy into random magnetosonic waves.

INTRODUCTION

A region with special interest in the interplanetary space as concerns the MHD turbulence is that of a CIR. Such a case has been examined recently by Mavromichalaki et al /1/ using Pioneer-10 and 11 observations at 5 and 2.5 AU. Hodogram analysis suggested the dominance of near plane polarized transverse Alfvenic mode fluctuations with periods between 2 min and one hour or more.

The purpose of this work is a further examination of this CIR at 2.5 AU during the days 284, 285, 286 of the year 1973, in a detailed manner using Pioneer-11 observations. An attempt has been made in order to identify the dominant microscale MHD modes that contribute to the turbulence of this area and form its microscopic structure at that heliocentric distance.

METHOD OF STUDY

For our study we have used data from Pioneer-11 magnetometer for the days 284, 285 and 286 of the year 1973. The time resolution of the interplanetary magnetic field samples is 0.75 sec while the radial plasma velocity measurements were taken every 5 minutes.
A Blackman and Tuckey power spectrum and a Fourier analysis have been carried on all the available magnetic field data. A set of well defined periods have been found at a confidence level 99.9% with the most of them in the order of some minute up to 15 min. This fact leads us to primarily investigate the small periodicities of our data in order to determine their weve

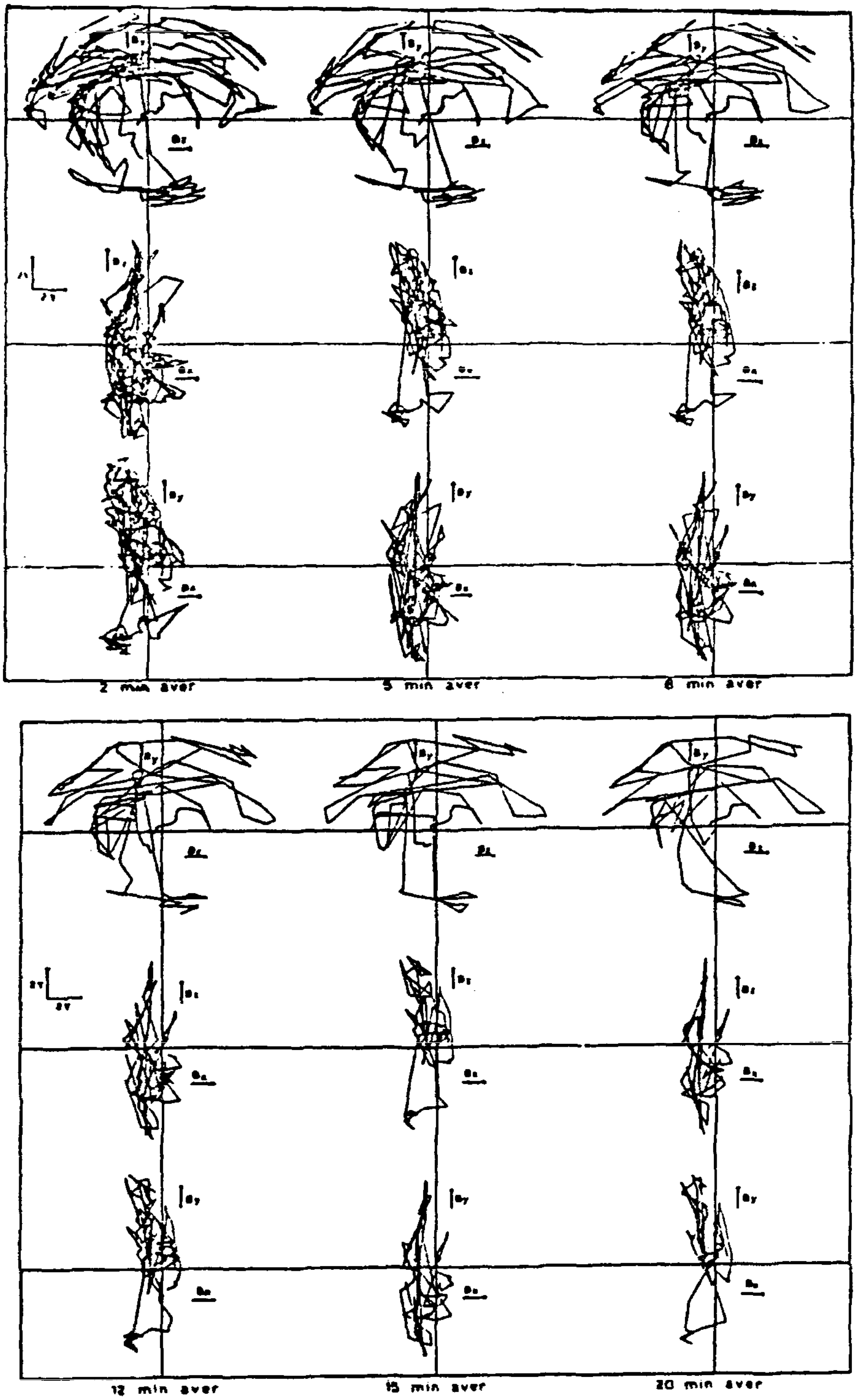

Fig. 1. Hodograms of the field components (284 day). Averages over two min up to 20 min intervals. The field vector in the (Y-Z) plane follows almost circular arcs with a roughly linear relation in the (X-Y) and (Z-X) plane.

structure. An hodogram analysis shows that a strong wave structure is dominant for field values averaged over two min to about 8 min intervals. This wave structure disappears if longer averages are used (Fig. 1). In order to define the polarization plane of the observed wave structure, we examined the anisotropy in the microscale fluctuations of the magnetic field data considering directions of maximum and minimum power in a preferred co-ordinate system, according to the method employed by Sonnerup and Cahill /2/. For this we estimate the variance tensor S which is defined by

$$S_{ij} = \langle B_i B_j \rangle - \langle B_i \rangle \langle B_j \rangle$$

Where i,j refer to X,Y,Z components of the magnetic field B and the angle brackets denote averaging over the chosen 15 minute time interval. The matrix S can be diagonalized, yielding the eigenvalues $L_1 \geq L_2 \geq L_3$ and the corresponding eigenvectors M_1, M_2, M_3. M_1 is the direction of maximum variation and M_3 is the direction of minimum variation. The relative magnitudes of the eigenvalues provide information about the anisotropy that is independent of the coordinate system used. Applying the above method in our data sets we find that in most of the cases the eigenvalue L_1 was much larger than L_2 and L_3 and subsequently the IMF fluctuations are primarily in the direction of the maximum variance M_1. So we expect the polarization to be primarily linear (Fig 2).

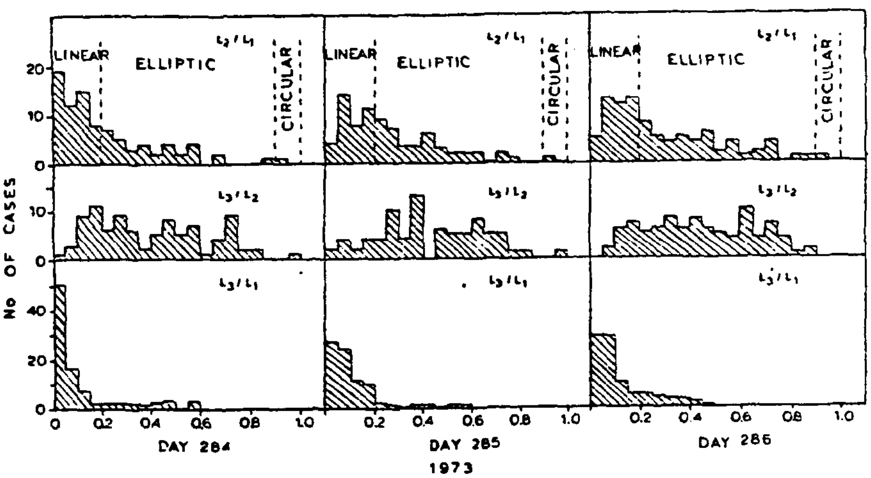

Fig 2. Eigenvalue ratios for each day under study

In order to confirm the non existence of circular polarization of the wave modes and to classify the MHD wave type, we have carried out to our data a coherency and phase lag analysis between the field components. We use this analysis to identify field fluctuations for frequencies 1.1×10^{-3} to 6.6×10^{-2} Hz. It is known that MHD wave modes exhibit numerous phase relationships between the field components and magnitude fluctuations some of which will be common to more than one mode. However according to Sari and Valley /3/ and Sari /4/ there are specific phase relationships which are unique to each mode and which can be determined from the analysis of the particular modes. In order to determine these modes by applying the coherence analysis we have estimated the orientation of the mean magnetic field for each examined day. it is characteristic that the mean magnetic field in 284 day is statistically oriented towards the Y - axis, during 285 day is oriented towards X - axis and in 286 day is approximately oriented in the mean spiral direction. The coherency and the phase lag between the three field components $(\Delta B_x, \Delta B_y, \Delta B_z)$ and the field magnitude ΔB is calculated for every

15 minute interval for the three days. The same quantities are also calculated between the magnitude of the transverse fluctuations $((\Delta B_x^2+\Delta B_z^2)^{1/2}$ for the day 284 and $(\Delta B_y^2+\Delta B_z^2)^{1/2}$ for the day 285) and the longitudinal fluctuations $(\Delta B_x, \Delta B_y)$ and ΔB at a confidence level of 99.9% when the coherency was greater than o.4 and exhibited near stable phase over a frequency band of greater than $f_c/4$, where $f_c = 6.6\times10^{-2}$ Hz.

It is noteworthy that there is no evidence of circular polarized wave modes (high coherency and near stable phase $\pm 90^o$ between ΔB_x - ΔB_z for 284 day or ΔB_y -ΔB_z for 285 day and all combinations for 286 day /3/). The most dominant wave modes during all days were the magnetoacoustic waves (high coherency and near stable phase 0^o or 180^o between field fluctuations ΔB and ΔB_x, ΔB_y and or ΔB_z for all days). There is an exception in day 286, where some small amplitude Alfven waves (high coherency and near stable phase 0^o between the transverse fluctuations and the field magnitude fluctuations) are appeared, at frequencies 4.4×10^{-3} - 6.6×10^{-2} Hz.

CONCLUSION

Summarising we can say that the dominant wave modes in the microscopic structure of the examined CIR, as resulted from the coherence analysis are the fast magnetoacoustic waves, with characteristic periods 15-900 sec. There is no evidence of circularly polarized Alfven waves or finite amplitude Alfven waves at this period range. A few small amplitude Alfven waves are found at smaller characteristic periods, (15-225 sec) in day 286 during the trailing edge of this region. The observed fast magnetoacoustic modes are locally generated and may be attributed to the scattering of Alfven wave energy, which are the waves of longer periods, into random magnetosonic waves /5/. The most appropriate explanation for the local character of the observed magnetosonic waves is that conversion of Alfven waves into magnetosonic waves is allowed through scattering by turbulent density fluctuations.

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REFERENCES

1. H. Mavromichalaki, X.Moussas, J.J Quenby, I.F. Valdes-Galicia, E.J. Smith and B.T. Thomas, Relatively stable large amplitude Alfvenic waves seen at 2.5 and 5.0 AU, *Solar Phys.*, 116, 377-390 (1988)

2. B.U.O. Sonnerup and L.H. Cahill, Magnetopause structure and attitude from Explorer 12 observatiuons,*J. Geophys. Res.*, 72, 171 (1967)

3. J.W Sari and G. Valley, Interplanetary magnetic field power spectra:mean field radial or perpendicular to radial,*J. Geophys. Res.*, 81, 5489-5499 (1977)

4. J.W. Sari, On the existence of finite amplitude transverse Alfven waves in the interplanetary magnetic field, Report x-692-77-170, Goddard Space Flight Center (1977)

5. G.C. Valley, Scattering of Alfven waves by random density fluctuations, *Astrophys. J*, 188, 181-189 (1974)