CONTRACT NASW-98001
PROGRESS REPORT

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Submitted by

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Background:
This grant seeks to analyze the broad range of Heliospheric Missions data to test and further develop current ideas on the nature and development of magnetohydrodynamic (MHD) turbulence in the solar wind. Recent modeling and simulation efforts have led to specific expectations for the anisotropy of the solar wind fluctuations both in the configuration space of the magnetic field and velocity vectors ($\delta\mathbf{b}(\mathbf{x})$ and $\delta\mathbf{v}(\mathbf{x})$) and in the wavevector space ($\delta\mathbf{b}(\mathbf{k})$ and $\delta\mathbf{v}(\mathbf{k})$). We use the spacecraft data to examine traditional measures such as power spectra, Alfvénicity, pressure-balance correlations, and variance ratios as a function of θ_R, the angle between the mean magnetic field $\mathbf{B}_0$ and the solar wind velocity $\mathbf{V}_{SW}$.

During the first two years of this project, we developed a method for extracting the individual reduced spectra of up to three separate components from a single spacecraft time series. Here "component" refers to current MHD turbulence perspectives on the composition of typical solar wind fluctuations. An earlier perspective, the two-component model, views solar wind fluctuations as composed of field-aligned Alfvén waves (Component 1, *e.g.*, slab turbulence) and 2D fluctuations with wavevectors and vector components purely orthogonal to the mean magnetic field (Component 2, *e.g.*, $\delta\mathbf{b} = \delta\mathbf{b}_\perp(\mathbf{k}_\perp)$). This slab-2D description of solar wind fluctuations has been used to explain two-component features in 2D magnetic correlation functions of solar wind turbulence (Matthaeus *et al.*, J. Geophys. Res., **95**, 20,673 (1990)). Unfortunately, the slab-2D description ignores structures such as magnetic pressure-balanced (PB) structures and velocity shears. In the MHD turbulence description, a PB structure is composed of parallel variances and orthogonal wavevectors in the magnetic field (*e.g.*, $\delta\mathbf{b} = \delta\mathbf{b}_{||}(\mathbf{k}_\perp)$). Similarly, a velocity shear is composed of parallel variances and orthogonal wavevectors in the velocity field (*e.g.*, $\delta\mathbf{v} = \delta\mathbf{v}_{||}(\mathbf{k}_\perp)$). Ghosh *et al.* (J. Geophys. Res., **103**, 23,705 (1998)) showed how an alternate two-component model, slab fluctuations and magnetic pressure-balanced structures, can develop 2D magnetic correlations similar to the standard slab-2D two-component model. The methodology developed from the HMGI grant permits separation of slab and 2D fluctuations from magnetic pressure-balanced structures (and eventually, slab and 2D fluctuations from velocity shears). Hence, our technique allows extraction of up to three components – slab, 2D fluctuations, and structures – from solar wind fluctuations. A paper describing this 3-component approach has been published (W. H. Matthaeus and S. Ghosh, "Spectral Decomposition of Solar Wind Turbulence: A Three-Component Model," *Solar Wind 9* (ed. S.R. Habbal, R. Esser, J.V. Hollweg & P.A. Isenberg, AIP Press, 1999) p. 519; hereafter, Paper 1).

We developed a Fortran code that performs the 3-component analysis. The code performs the following operations:

A subinterval is selected for analysis. A typical choice is 256 data points of magnetic field components in R-T-N coordinates sampled at 5-min or 10-min averaging. This subinterval is rotated into mean magnetic field coordinates using the average field of the subinterval as the mean magnetic field. The time series is Fourier transformed into a wavenumber (k) spectrum based on assumptions of stationarity. Knowledge of the local solar wind speed is also needed. Additional subintervals are accumulated following the above three steps. The accumulated averaged reduced spectrum is solved for its three underlying components based on Eqs. (11) – (13) from Paper 1. This is the heart of our analysis procedure.

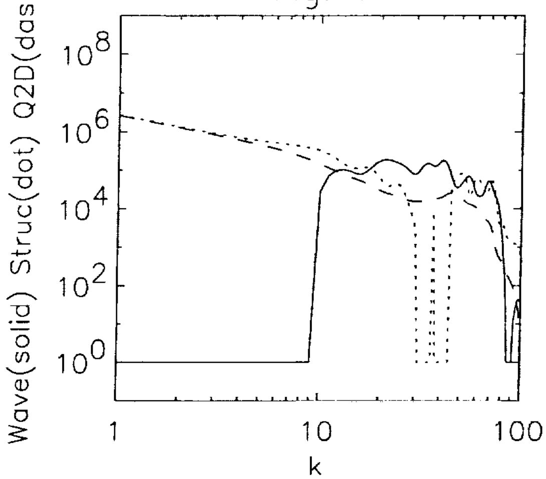
Paper 1 suggests using a tridiagonal matrix solver to extract the three components during step 5 above. During the second year, we determined that Eqs. (11) – (13) from Paper 1 can be solved by direct integration if properly constructed boundary conditions at k_{min} and k_{max} are specified. This modification has been implemented. We have also modified the code to study angular dependencies.

The success of our method depends on using data that passes stationarity tests. The ISEE-3 data that were used for first-year tests had already been tested for stationarity. During the second year, we assembled data samples from other heliospheric missions. Data include 1-minute datasets from Ulysses, additional 5-minute samples from ISEE-3, 10-minute averages from the Pioneer Venus Orbiter, as well as 1-hour Voyager and Omnitape data. These data must also be checked for stationarity.

We obtained the collaboration and assistance of Dr. Charles W. Smith, Bartol Research Institute, Univ. of Delaware, for the analysis and reduction of these additional datasets.

Work performed during the current period:
Analyses of ISEE-3 and PVO data continue to show that quasi-2D turbulence structures and PB structures are energetically almost equally dominant at time periods greater than 2-3 hours (large scales). PB structures are somewhat more dominant at scales below 2-3 hours, with field-aligned slab modes dominating smaller scales (less than 1 hour). The following three figures, repeated from the Year 2 report, confirm our central finding. Figure 1 shows a typical case from ISEE3 data. Field-aligned waves are the solid line, PB structures are the dotted line, and quasi-2D turbulence is the dashed line. This breakdown is obtained after averaging over all θ_R

Fig. 1



angles. Dividing our samples into bins of θ_R angle gives new insights. At large θ_R ($\theta_R > 70$ degrees), Figure 1 continues to represent the typical scenario. At intermediate θ_R ($\theta_R \sim 45$ degrees) quasi-2D turbulence and PB structures dominate with little evidence of field-aligned wave fluctuations, as shown in Figure 2. At small θ_R ($\theta_R < 10$ degrees), as shown in Figure 3, field-aligned wave-like fluctuations dominate at all scales.

Fig. 2

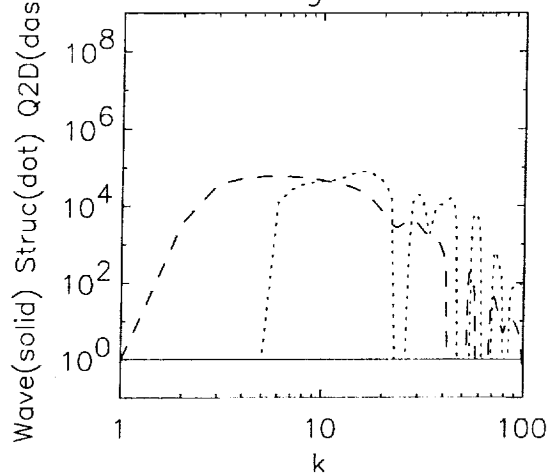
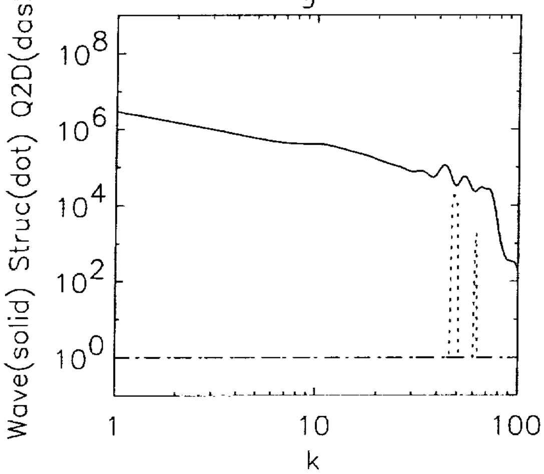


Fig. 3



These findings, originally presented during Year 2, are upheld with the time intervals we have analyzed so far during Year 3. During Year 3, we plan to include IMP-8 (avoiding electron foreshock effects), Wind, and ACE data.

Currently, we are in the midst of the following work:

We believe that our 3-component analysis can be modified to include highly oblique Alfven waves (oblique to the mean magnetic field direction). We are trying to recast our analysis to account for highly oblique waves.
We are analyzing magnetic field correlations from the IMP-8 spacecraft as a function of the θ_R angle. Variance analyses are planned as well.
A manuscript is in preparation for publication of our results.

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13. ABSTRACT *(Maximum 200 words)*

This grant seeks to analyze Heliospheric Missions data to test current theories on the angular dependence (with respect to mean magnetic field direction) of MHD turbulence in the solar wind. Solar wind turbulence may be composed of two or more dynamically independent components. Such components include magnetic pressure-balanced structures, velocity shears, quasi-2D turbulence, and slab (Alfvén) waves. We use a method, developed during the first two years of this grant, for extracting the individual reduced spectra of up to three separate turbulence components from a single spacecraft time series. The method has been used on ISEE-3 data, Pioneer Venus Orbiter (PVO), Ulysses, and Voyager data samples. The correlation of fluctuations as a function of angle between flow direction and magnetic-field direction is the focus of study during the third year.

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