Solar Modes in the Heliosphere

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Abstract

Fluctuations in interplanetary magnetic fields and particle fluxes are largely driven by the normal modes of the Sun. We examine propagation between the ACE and Ulysses spacecraft using both magnetic fields and spherical harmonic coefficients of electron fluxes from the EPAM and HISCALE instruments. There are typically four families of propagating modes, whose orientations appear to be determined by the Parker spiral. The different orbits of the two spacecraft are used to help identify modes. Time series of slopes of the background spectrum using short, overlapping blocks also show systematic variations.

1 Introduction and Background

During the last decade we have challenged the view that fluctuations in the interplanetary magnetic field and charged particle fluxes are primarily a result of turbulence and have attributed the majority of the observed fluctuations to discrete frequencies driven by normal modes of the Sun. These modes were orginally noticed during a study of satellite failures around the 1990 solar maximum, and reported in [6, 7]. In [8] we demonstrated coherence between hourly averages of 38–100 keV electron fluxes measured by the EPAM and HISCALE instruments on the ACE and Ulysses spacecraft, respectively. In [9] we expanded on our analysis methods, gave further examples, and showed where the criticisms, *e.g.* Roberts *et al.* [4], Riley and Sonett [3] of Thomson *et al.* [6] failed. The study Thomson *et al.* [10] gave more examples of high–Q lines in particle fluxes with frequencies in the solar g–mode band, and Thomson [5] showed that modal signatures were clearly evident in spherical harmonic coefficients of the SOHO MDI magnetograms. Most recently Thomson *et al.* [11] we gave extensive background on solar modes, various factors that complicate interpretation, analysis methods, and showed: 1) coherence between the magnetic fields at ACE and Ulysses using data with a one–minute sampling rate; 2) the ellipticities of the coherent modes at ACE and Ulysses are essentially identical, although their orientations appear to track the Parker spiral and so are different at the two spacecraft; 3) high coherence between ACE and WIND, ACE and GOES-10, and ACE and the South Pole magnetometer. We also showed coherence between solar radio flux and the dropped call rate in cellular phone systems, and most surprising, between the magnetic fields at ACE and seismic noise on Earth. Various other results include detection of solar modes in various data at both lower and higher frequencies than the commonly observed solar p–modes. In particular, power spectra of voltages induced on California to Hawaii ocean cables have series of strong peaks separated by the $\sim 136\,\mu$Hz spacing characteristic of solar p–modes at frequencies *above* the acoustic cutoff frequency of ~ 5.1 mHz, [1] of the Sun. These are also detectable in ACE and geomagnetic observatory data to frequencies up to at least 50 mHz. Such modes have been predicted, see *e.g.* [2], but we have not found previous reports of their detection at such high frequencies. Unlike the optically observed "pseudo modes", the modes observed on the cables and in magnetic fields have high Q's.

2 Summary of New Results

In this paper we report new results on the statistics of the IMF and propagation between ACE and Ulysses. Averaged over a year, the *background* spectrum of the IMF near Earth has an approximately $f^{-5/3}$ spectrum characteristic of Kolmogorov turbulence. It is, however, nonstationary. We have computed spectra on many short (less than one day) segments of IMF data and computed the slope (on a log–spectrum, log–frequency scale) over a frequency range that begins above solar rotation and stops short of the Nyquist frequency $sim8.3$ mHz. Analysis of time series of these slopes show that they vary in a systematic manner. For example, the range of slopes on 17–hour blocks, chosen to minimize possible harmonics of the day, of 1–minute samples of the GSE-X component of the magnetic field at ACE during 1999 ranged from -1.301 to -2.513 with an average of 1.706, a standard deviation of 0.141, and a somewhat non–Gaussian distribution. The spectrum of this series was surprising in that solar rotation was *not* evident, but many large peaks at significance levels well above the 99.9% significance level were observed in the 2 to 10, and the 20 to 30 μHz ranges. Thus the changes in the slopes of the spectrum are partialy determined by high–Q oscillations, possibly R– and g–modes.

We also report new results on propagation between ACE and Ulysses using both vector magnetic fields and the $l = 1$ spherical harmonic coefficients derived from the 16 sectors of electron fluxes from the $E2$, $E'2$, and $DE2$ detectors (all ~ 60 to 100 keV) of the HISCALE and EPAM instruments on Ulysses and ACE. (EPAM is the backup for HISCALE, so these are well–matched instruments.) Analysis of the multivariate time series consisting of three magnetic and three electron spherical harmonic series shows that the spectral matrix has four large eigenvalues and two that are much smaller. We interpret this as showing that there are four propagating modes.

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