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Solar polarity dependence of power spectra from Mawson underground observations

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Abstract

Power spectral analysis of Mawson underground data was undertaken to study cosmic ray modulation and its magnetic polarity dependence over the last three solar cycles. The first two harmonics of the solar daily variation are well defined for even cycles (20 and 22) while only the first harmonic is well defined in cycle 21. The spectrum is flatter in the even cycles. There is higher spectral power for cycle 21. The spectra are flatter and have lower power for qA>0 than for qA<0 polarity states in support of the predictions of modulation models. The spectra imply that heliospheric magnetic turbulence may be more variable, on timescales of several years, than previously suspected.

1 Introduction:

Propagation and acceleration of galactic cosmic rays in the heliosphere is governed by four major mechanisms: diffusion, convection, and gradient and curvature drifts (Kota and Jokipii, 1983). A wavy neutral current sheet separates the heliosphere into two regions of opposite magnetic sense. During epochs of positive polarity (e.g. 1973–1979 and 1991–1998), the interplanetary magnetic field (IMF) is directed away from the Sun above the current sheet and toward the Sun south of the current sheet. For negative polarity epochs (e.g. 1981–88) the IMF direction is reversed. Positive polarity (qA>0) periods are characterised by galactic cosmic rays (of positively charge) drifting inward from the pole and exiting along the heliomagnetic equator and neutral sheet. Conversely during qA<0 the drift is inward along the helioequator and neutral sheet and out over the poles.

Jokipii (1971), Owens and Jokipii (1972,1974), Owens (1974), and Jokipii and Owens (1976) have related the fluctuations of neutron monitor power spectra to fluctuations in the IMF. Yasue et al. (1995) and Sabbah (1997) have studied the spectra of high energy cosmic rays with a view to learning more about the interstellar media. In this analysis the power spectral density (PSD) has been calculated for cosmic rays observed with the underground north pointing muon telescopes at Mawson from 1973–1998.

2 Data Analysis:

Power spectral densities were calculated, following the procedure described by Sabbah (1997), for 1973–76 (cycle 20), 1977–85 (cycle 21), 1986–96 (cycle 22), 1997–98 and for both heliomagnetic polarity states. These are shown in Figure 1. The spectral power of the odd cycle (Figure 1b) exceeds those of the even cycles (Figure 1a & c). The odd cycle spectrum is also steeper. Spectral power is higher for cycle 20 than for cycle 22. The first two harmonics of the solar daily variation are well defined for even cycles while only the first harmonic is well defined in the odd cycle. The bottom panels of Figure 1 show the spectra for both heliomagnetic polarity states. The spectrum has higher power density during qA<0 than during qA>0. This agrees with predictions of numerical drift models (Reinecke and Potgieter, 1994).

The spectrum is steeper during qA<0. All the spectra flatten at the higher frequencies shown but the form of the flattening is markedly different between the two polarities. Above about 3×10^{-5} Hz (<9 hours) the spectra in both polarity states are quite similar. Below this frequency the spectra diverge greatly with the qA<0 polarity following a power law form with a slope of -1.89. Superimposed on this is a clear peak corresponding to the diurnal (24 hour) variation and a suggestion of a peak at 12 hours. In the qA>0 case the spectrum is more variable and does not appear to follow a power law structure until the lowest frequencies. There is still clear evidence of the diurnal variation signal and weak evidence for a semi-diurnal peak.

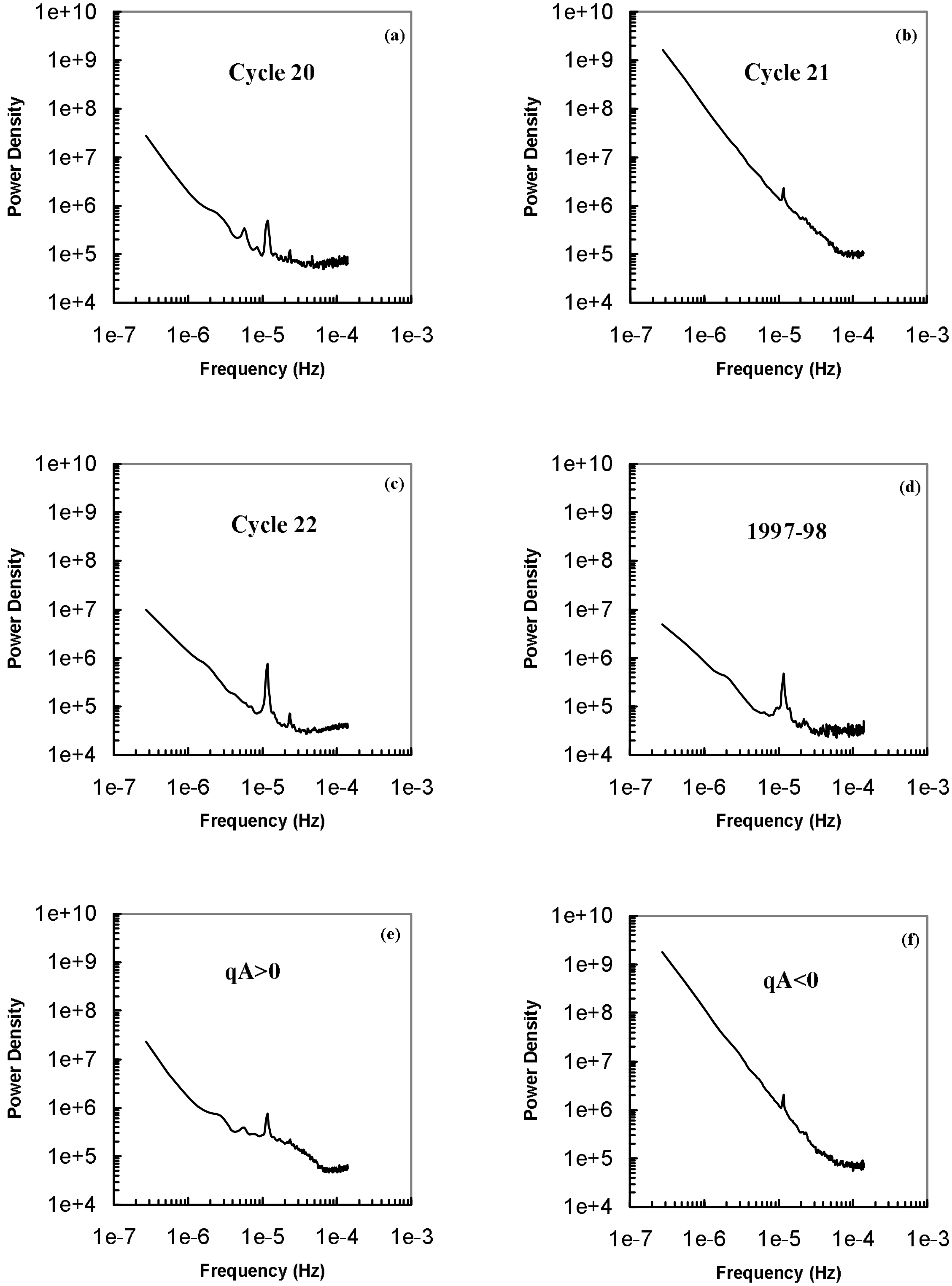

Figure 1: Power Spectral Densities derived from hourly underground observations at Mawson.

3 Discussion:

Following from the work of Owens (1974), Yasue et al. (1995) showed that $P(f)^{1\mu Hz} / P(f)^{peak} = P^B(f) / B_0^2$, where $P(f)^{1\mu Hz}$ is the power at 1μHz, $P(f)^{peak}$ is the power of the diurnal variation peak, $P^B(f)$ is the power spectrum of magnetic field fluctuations and B_0 is the ensemble average magnetic field intensity. The ratio from cosmic ray observations was then employed to estimate the relative magnetic turbulence in interstellar space compared to that present in the heliosphere.

Period	Cycle 20	Cycle 21	Cycle 22	1997–98	qA>0	qA<0
$P(f)^{1\mu Hz} / P(f)^{peak}$	3.39	40.0	1.55	1.53	1.87	48.6

In the table, the ratios for each solar cycle, 1997–98 and both solar polarity states are given. These values should be compared with those of Yasue et al. (1995) for the Misato observatory, which is at a similar depth (median rigidity) to Mawson. Yasue noted the large variation in the ratio between Sakashita and Matsushiro even though they have similar median rigidities. In these results it is clear that the ratio is much larger over the longer time periods considered here and that there is strong variability either between polarity states or between different time periods (as denoted by the solar cycles). From their analysis, Yasue et al. (1995) concluded that the different ratios at different median rigidities might indicate that the local interstellar magnetic field is more turbulent than the heliospheric field. From the results presented here, it would seem more likely that the heliomagnetic field turbulence varies much more than widely than previously thought. A more detailed investigation of how the ratio varies with time and median rigidity of response particularly between solar maximum and solar minimum conditions in each polarity state is planned.

4 Conclusion:

A maximum entropy power spectral analysis of Mawson underground data has shown that there is higher power density during qA<0 than during qA>0. This agrees with predictions of numerical drift models (Reinecke and Potgieter, 1994). It has been shown that the ratio of spectral power at 1μHz to the spectral power of the diurnal variation is highly variable. This may be interpreted as indicating that the heliomagnetic turbulence is more variable on timescales of years than had been previously suspected. It will be valuable to undertake the analysis on different timescales to better understand this variability. A useful first step would be to consider solar maximum and solar minimum periods in different polarity states. This work is continuing.

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