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Propagation of Energetic Particles to High Heliographic Latitudes

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Abstract. The Ulysses spacecraft has now completed its second orbit over the poles of the Sun. Energetic particles associated with CMEs were observed at the highest latitudes over both poles, quite unlike the first polar pass when virtually no CME or CIR accelerated particles were observed at the very highest latitudes. We present observations of solar energetic particle events observed in the energy range ∼1 MeV to ∼100 MeV made by the COSPIN instrument, when the spacecraft was at high heliographic latitude over the northern pole, above the current sheet, and immersed in high-speed solar-wind flow coming from the northern polar coronal hole. We discuss the rise to maximum, the onset time and the anisotropy of the energetic particles. We find that, unlike the events observed at mid and low latitudes, the particle angular distributions were almost isotropic, but with a net outward flow along the magnetic field lines. We compare these events with other events observed at lower latitudes.

Keywords. Sun: coronal mass ejections (CMEs), particle emission, solar wind

Keywords. Ulysses, energetic particles, propagation, coronal mass ejection, anisotropy

1. Introduction

In February 1992 the Ulysses spacecraft used an encounter with the planet Jupiter to begin its first out-of-the-ecliptic orbit around the Sun, completing it in April 1998. This orbit began as the level of solar activity was falling. Most of the time when the spacecraft was over the south and then over the north pole of the Sun was close to the time of minimum of solar activity of solar cycle 22.

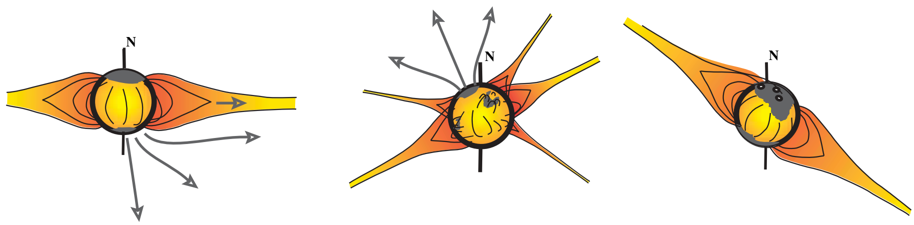

Figure 1. Cartoon showing the coronal magnetic field observed during, from left to right, (a) the first polar passes, (b) the second southern polar pass. and (c) the second northern polar pass (Adapted from Suess et al., 1998).

At this time the axis of the dipolar component of the coronal magnetic field was nearly parallel to the Sun's spin axis, and the current sheet was almost flat, giving rise to a streamer belt which was more or less in the plane of the ecliptic. Large coronal holes were observed over the poles, giving rise to high-speed solar-wind flow in the high latitude polar regions of the heliosphere. Figure 1a, after Suess et al. (1998) shows this configuration.

As this was a period close to solar minimum, very few particle increases due to either Coronal Mass Ejections (CME) or Co-Rotating Interaction Regions (CIR) were observed in the polar regions during these passes. At mid-latitudes, significant increases due to CIRs were observed for a substantial fraction of the time that the spacecraft was above the current sheet, but again at the very highest latitudes very few, if any, were observed.

The second orbit around the sun began in April 1998 as the level of solar activity of solar cycle 23 was increasing. The second orbit was considerably different from the first. During most of the orbit, the heliosphere was dominated by the presence of CMEs as the level of solar activity increased, the spacecraft passing over the south and then the north poles of the Sun during the time around the maximum of solar activity of solar cycle 23. A summary of Ulysses observations during the maximum of cycle 23 can be found elsewhere in this volume (Marsden, 2004).

Conditions on the Sun were very different for the southern and the northern polar passes (Sanderson et al., 2003a, Sanderson, 2004). During the southern pass (Figure 1b), the dipole axis was oriented at around 135 degrees to the spin axis and the field had a significant quadrupole component. The current sheet reached up to very high latitudes, and there was no polar coronal hole over the southern pole, typical of that expected around solar maximum. So, Ulysses remained in slow solar wind flow as it passed over the pole.

Over the northern pole (Figure 1c) the situation was quite different. The tilt of the dipole was similar. The dipole strength had increased, and the quadrupole term of the coronal field had diminished. The field was therefore much more dipolar, and so the current sheet only reached up to mid latitudes. A polar coronal hole had started to develop, and by the time Ulysses reached the highest northern latitudes it was immersed in fast solar wind. Although the northern pass was still close to solar maximum, the configuration of the Sun was beginning to look more like that close to solar minimum.

Solar activity was still high, and so perhaps not surprisingly, CMEs and substantial particle increases were observed at the highest latitudes as the spacecraft passed over the northern pole of the Sun. Several large SEP events were observed at high latitude and in the fast solar wind. These events were unusual in that they were the only CME-related particle increases observed so far by Ulysses at high latitudes and in the fast solar wind. They were also unusual in that the onsets at high energies were delayed considerably, and the angular distributions at onset were almost isotropic.

In this paper, we discuss the propagation of energetic particles to high heliographic latitudes as observed when Ulysses was over the northern pole and immersed in the fast solar wind, and compare them with events observed in the slow solar wind over the southern pole.

2. The Second Northern Polar Pass

We begin by discussing the northern polar pass. In Figure 2 we show summary plots of the events number 2, 3 and 4 of Sanderson et al. (2003b). These events have also been studied in detail by Dalla et al. (2003a, 2003b), Lario et al. (2004) and McKibben at al. (2003). An additional event, Event 1, is included here as a typical event observed close to Earth. Event 1 was observed shortly after Ulysses had been launched, 11 November (day 315) 1990.

Each plot covers 16 days. Each is split into three panels. In the bottom panel we show particle intensities from two electron channels ranging from 1 to 10 MeV, in the next,

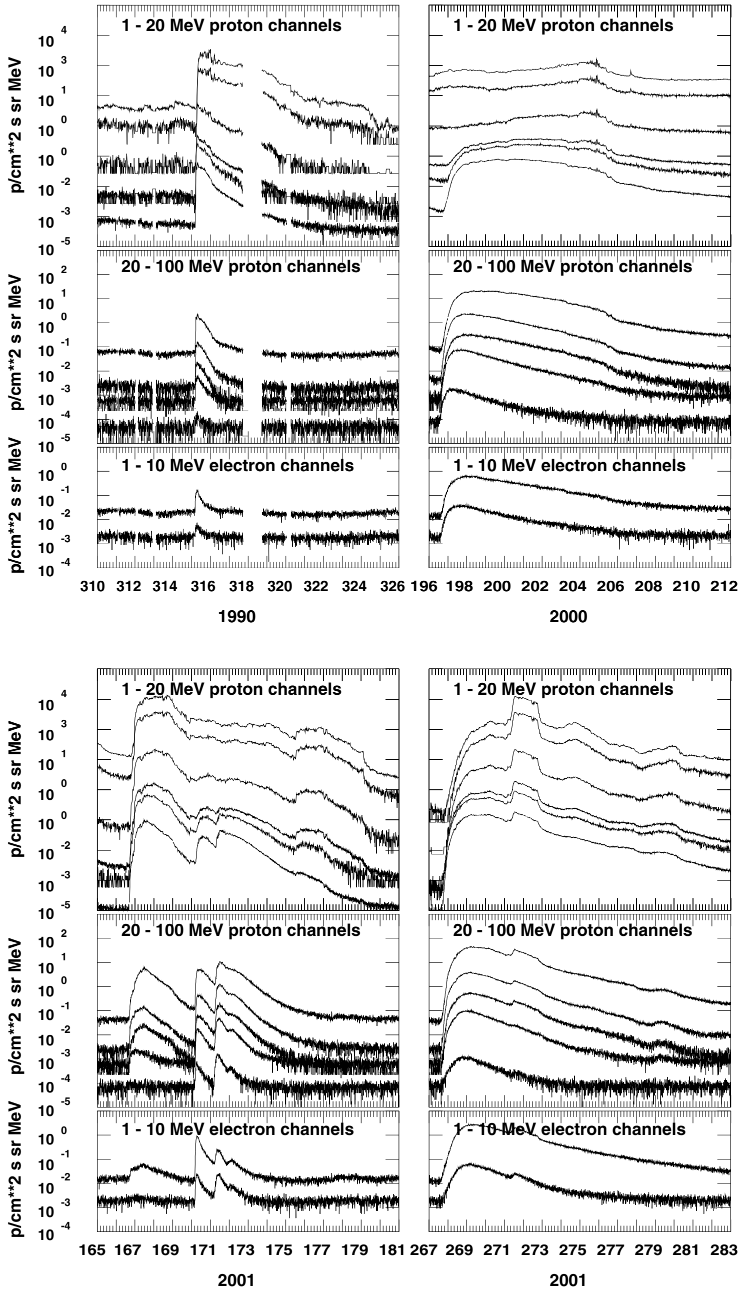

Figure 2. 16-day summary plots for events 1, 2, 3, and 4. The bottom panel of each plot shows particle intensities from 2 electron channels ranging from 1 to 10 MeV, in the next, from 5 proton channels ranging from 100 MeV to 20 MeV, and in the top panel, from 6 proton channels ranging from 20 MeV to 1MeV.

from 5 proton channels ranging from 20 MeV to 100 MeV, and in the top panel, from 6 proton channels ranging from 1 MeV to 20 MeV.

Event 1 was observed shortly after Ulysses had been launched and was on its way to Jupiter, being at a radial distance of 1.07 AU and heliographic latitude of just 4° and is

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included here as an example of a 'typical' 1 AU event for our instrument. Note the rapid onset, typical of events like this at 1 AU.

Event 2 is the Bastille-day event, observed at mid-latitudes and in the slow solar-wind. The onset and decay profile in the electron channels and at high proton energies was relatively smooth (bottom and middle panel). A high background masked the onset of the event at low proton energies (top panel).

Event 3 is typical of the many low-latitude events, where the event occurs at the same time as a structure in the magnetic field such as a CIR or SIR passes the spacecraft during the onset. The time intensity profile during the first onset was considerably disturbed by the presence of the structure, parts of which acted as channels to allow the lower energy protons rapid access to the position of the spacecraft, and other parts of which acted as sources of local acceleration. This gave rise to complicated intensity versus time and anisotropy parameters versus time profiles. This is the most often seen type of event at Ulysses.

Event 4 is one of the few large high-latitude events observed in the fast solar wind during the Ulysses mission, as observed during the second high-latitude pass. This event had a relatively slow onset (compared with 1 AU in-ecliptic events) and during the first few days, a smooth time-intensity profile. The CME which followed a few days after the onset showed up as an increase lasting around 1 - 2 days in the low energy particle intensity.

In Figures 3 and 4 we show particle intensity profiles and anisotropy parameters for two events, taken from Sanderson et al. (2003b). Here we show, from top to bottom, the following: low energy proton intensities, 1.8 - 3.8 MeV first order perpendicular anisotropy, first order parallel anisotropy, high energy proton intensity, 34 - 68 MeV first order perpendicular anisotropy, first order parallel anisotropy, magnetic field azimuth, elevation (in spacecraft coordinates), and magnitude. The particle instruments scan in a plane perpendicular to the spacecraft spin axis (z-axis), where the z-axis always points to the earth. After rotating the x-axis to the direction of the magnetic field projected onto the scan plane, the sectored count rates in this frame of reference are Fourier analysed. In this way, the 2-dimensional parallel and perpendicular anisotropy amplitudes in the scan plane are derived. Anisotropies presented here are the ratios of the amplitude of the first order component in the scan plane (either parallel or perpendicular to the projected field direction) to the amplitude of the zero order component.

Figure 3 is a 3-day plot showing the onset of event 1, observed on 11 November (day 315), 1990, the 1 AU baseline event. This event has a profile similar to profiles described in many models of propagation, but in fact was one of the rare occasions when we observed an onset without the disturbing effect of the presence of a magnetic field structure such as a CIR, SIR, or CME at the spacecraft.

The 34 - 68 MeV parallel anisotropy suddenly increased at the time the 34 - 68 MeV intensity started to rise, and dropped to zero within a few hours of the onset. Similarly, the 1.8 - 3.8 MeV anisotropy rose and fell, starting one or two hours after that of the 34 - 68 MeV particles. In both cases, during the rise to maximum, and for a few hours thereafter, there was a finite parallel anisotropy and a perpendicular component which was essentially zero, signifying that the particles are always field-aligned. The small fluctuations were mainly due to the limited counting statistics.

Compare this with the high-latitude, fast solar wind event in Figure 4. This shows in detail the September 2001 event. This is a 6-day plot, starting on 24 September (day 267), 2001. At high energies, the increase was about one order of magnitude less than the low latitude events. The event was most likely initiated by an X2.6 flare at 09:36 on 24 September, day 267, at S16 E23. This event has a moderately rapid increase at $\sim$50 MeV.

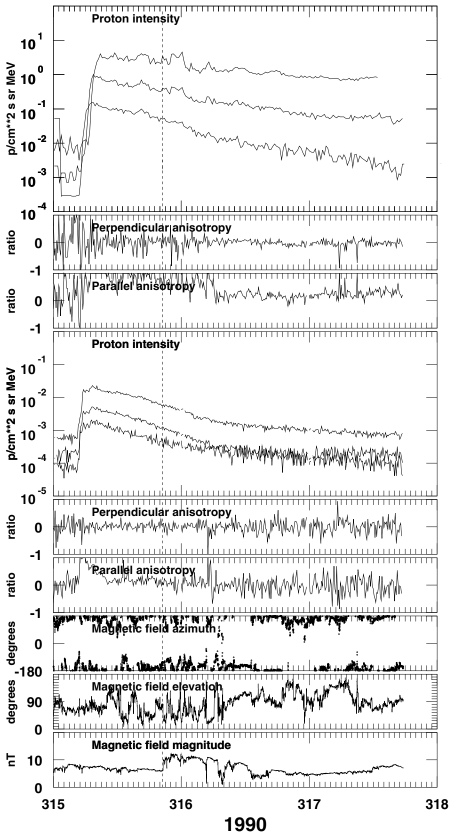

Figure 3. November 11 1990 event, from top to bottom, proton intensity from the 1.8 - 3.8, 3.8 - 8.0 and 8.0 - 19.0 MeV channels, 1.8 - 3.8 MeV first order anisotropy amplitude resolved perpendicular to the component of the magnetic field in the scan plane of the instrument, first order anisotropy amplitude resolved parallel to the component of the magnetic field in the scan plane of the instrument, proton intensity from the 24 - 31, 34 - 68 and 68 - 92 MeV channels, 34 - 68 MeV first order anisotropy amplitude resolved perpendicular to the component of the magnetic field in the scan plane of the instrument, first order anisotropy amplitude resolved parallel to the component of the magnetic field in the scan plane of the instrument, magnetic field azimuth, elevation (in spacecraft coordinates), and magnitude.

Three and one half days after the onset, an over-expanding CME (start and stop times shown by the long-dashed lines) (Reisenfeld et al., 2003), preceded by a forward shock (shown by the short-dashed line), passed the spacecraft, causing an additional increase of around one order of magnitude in the particle intensity at around ∼1 MeV. The event slowly decayed to background level after about 15 days.

In general, the duration of the events observed in the slow solar-wind events were shorter than the fast solar wind events, a typical slow solar-wind event lasting 7 - 10 days, and a typical fast solar-wind event lasting 15 days. Onsets at high latitude and in the fast solar-wind tended to be smooth and rapid, lasting typically one day. Surprisingly the anisotropies associated with the onset were very small.

Comparing event 1, the baseline 1 AU event with event 4, the high-latitude, high-speed flow event, we see immediately the large difference between the two. The 1 AU event rose to a maximum in around 3 hours. The intensity during the high-latitude event rose in

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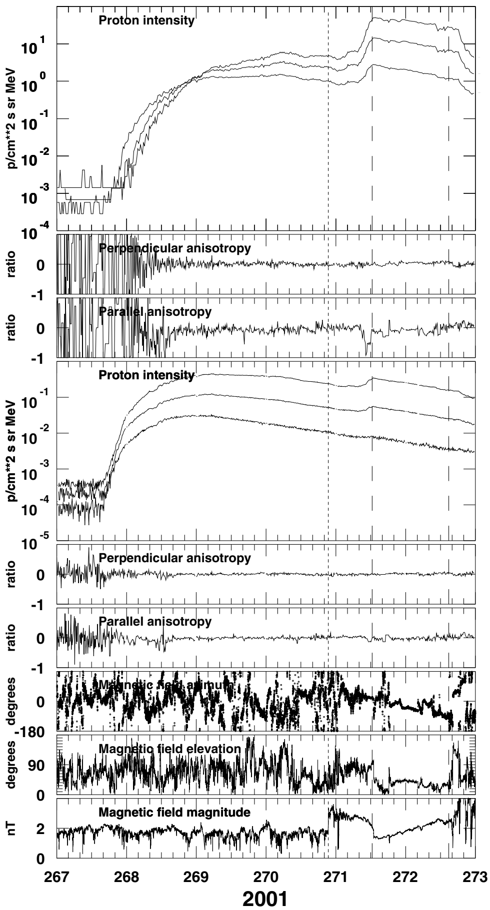

Figure 4. The September 2001 Event, plotted with the same parameters as in Figure 3.

around 2 days, a factor ~16 slower than the 1 AU event, which was located only a factor ~2 closer to the Sun (measured along the field line).

Larger than expected delays in onset times were observed for most of these high-latitude events (Dalla et al., 2003a, 2003b), corresponding typically to 120 to 350 minutes from the flare onset. These delay times and the path lengths were correlated by Dalla et al. (2003a, 2003b) against several variables. The best correlation was found with difference in latitude between the flare site and the latitude of Ulysses, this correlation being surprisingly better than the correlation with the angular separation between the site and Ulysses. This implies a very effective longitudinal transport of the particles, but a very inefficient transport latitudinally, which the authors concluded meant that cross field diffusion was the fundamental mechanism in getting the particles to high latitudes, in agreement with the suggestion by Zhang et al. (2003) for the Bastille Day event. However, they did not rule out the possibility that the delay was due to the time taken for the CME to reach the field lines connected to the spacecraft.

The anisotropy in the high-latitude event was very small. Note that the scales of the anisotropy panels are the same. In the 34 - 68 MeV channel, the component of the anisotropy perpendicular to the field fluctuated back and forth around zero. There was a small but finite anisotropy which persisted for around one day after the onset in the 34 - 68 MeV proton channel, signifying that the particles were propagating outwards from the

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Sun (the field direction at this time was inward). This anisotropy persisted until around the time of maximum of the 34 - 68 MeV channel, and then remained around zero for the next couple of days. All along, the perpendicular component remained around zero, indicating that there was no net flow across the field.

In the 1.8 - 8.0 MeV channel, the component of the anisotropy perpendicular to the field again fluctuated back and forth around zero. There was a larger negative parallel anisotropy which persisted for around half a day after the onset in the 1.8 - 3.8 MeV channel, again signifying that the particles were propagating outwards from the Sun. A small field aligned anisotropy persisted during the next couple of days. Again, all along, the perpendicular component remained around zero, indicating that the net flow was field aligned.

The measured anisotropies were very small. Within the limits of accuracy of measurement of the anisotropy, when there was a net flow, the anisotropy directions were coincident with the magnetic field direction, projected onto the plane within which the anisotropy measurements are made. This meant that the flow was field aligned, and that particles reached high latitudes traveling along the field lines, and not by crossing over them. The particles were scattered significantly as they propagate outwards, which explains their relatively slow onset and their small anisotropy, but despite this, any net flow direction was still along the local magnetic field line direction.

3. Discussion

At high latitudes and in the fast solar wind (70 - 80°N) we found no evidence for any substantial net flow across the field lines, whereas at moderately high latitudes in the slow solar wind (62°S) Zhang et al. (2003) found evidence for cross-field flow.

In Figure 5 we show data from the Bastille-day event, using the same format as in Figure 3. This event has some similarities to the high-speed, high-latitude events, Events 4 to 7. However, the Bastille event was observed in the slow solar wind and is more like a low latitude event (such as shown in Figure 3) than a high latitude one. At Ulysses, the Bastille Day event was an unexceptional event. The increase discussed here was a secondary event sometime after the main event. It was observed at 3.17 AU, and at 62°S, which was around the same southern latitude as the southern-most extent of the current sheet, whereas Events 4, 5, 6 and 7 were observed at 2 AU and latitudes between 70° and 80°N, which at the time was ∼20° higher than the northern-most extent of the current sheet.

The main event began with an onset at high energies at Ulysses on day 193. The second, more substantial onset occurred at around 1600 UT on day 197. The anisotropy of the high energy particles suddenly increased at the time of onset, the particles streaming outwards along the field past the spacecraft. The anisotropy amplitude then started to decrease. At the beginning of day 197, a CME arrived at the position of Ulysses. The magnetic field direction in the spacecraft frame of reference changed as the spacecraft entered the CME, reversing the sign of the anisotropy amplitude. The anisotropy amplitude continued to decrease as the spacecraft entered the CME, whilst at the same time a comparable, but small, perpendicular component of the anisotropy (measured in the scan plane) was observed. Half way through the passage of the CME, the anisotropy had dropped essentially to zero. Although at a moderately high latitude, this event was observed in the slow solar wind, and has some similarities to the 1 AU event shown in Figure 3. Upstream of the CME was a region lasting around 6 hours within which the high-energy anisotropy was high. The perpendicular component was considerably smaller, which implies that the flow was essentially field aligned. Immediately after the onset,

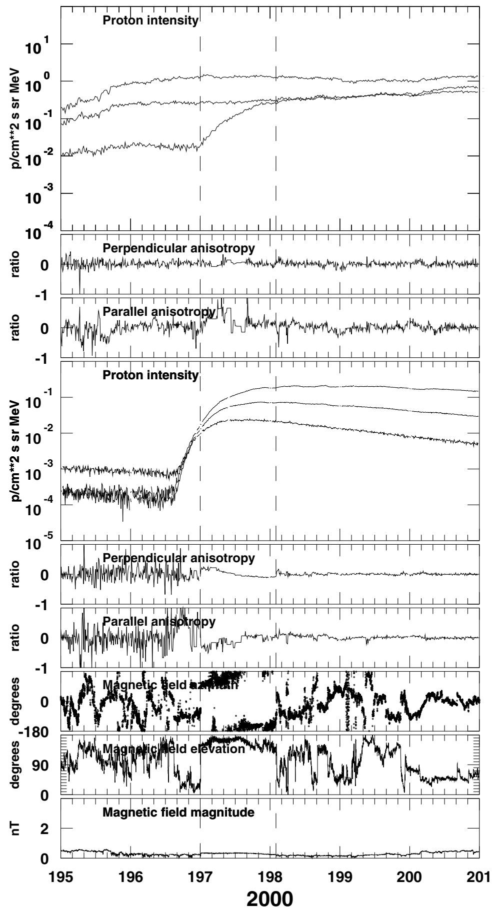

Figure 5. The Bastille day event, plotted with the same parameters as in Figure 3.

particles traveling along the field lines with a moderately substantial parallel anisotropy and essentially no perpendicular anisotropy were observed. The anisotropy amplitude then started to decay slowly, just like the 1 AU in-ecliptic event, except the time and magnitude scales were considerably different.

Approximately 10 hours after the onset, the spacecraft entered the previously-existing CME, quite unrelated to the CME which was responsible for this event. The parallel anisotropy amplitude continued to decrease, but from this time on a perpendicular component of similar magnitude was observed. Both the perpendicular and parallel component amplitudes continued to decrease until both were zero at a time half way through the passage of the CME. This could imply that particles were crossing field lines within the CME, as suggested by Zhang et al. (2003) although this is probably unlikely, as the field is usually very quiet inside a CME, so scattering across the field lines is not to be expected. A more likely explanation is that inside the previously existing CME there was a substantial un-measurable field aligned component, as at this time the magnetic field in the spacecraft frame of reference was almost perpendicular to the scan plane. This signature could also possibly be due to the existence of a gradient, but the duration of this anisotropy is probably too long for this to be true.

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4. Summary and conclusions

At solar minimum, most of the high latitude region is filled with fast solar wind. At solar maximum, only a few small low-latitude fast solar wind streams exist. For the study of particle propagation at high latitudes, it is important to differentiate between propagation in slow and fast solar wind, as the characteristics of the propagation differ considerably between the two.

During the southern polar pass, the spacecraft was continually in the slow solar wind. Most of the particle events observed at this time occurred at the same time as some other pre-existing and unrelated structure, such as a CME from a previous solar flare, or a CIR, passed over the spacecraft. Particle propagation was dominated by the presence of these structures, the frequent occurrence of which meant that it was quite rare to find an event where the event was unaffected by one. The forward and reverse shocks and the stream interfaces of the CIRs, and interplanetary shocks and magnetic clouds of the CMEs all affected the particle propagation, sometimes even accelerating the lower energy particles locally. These structures tended to be full of discontinuities, which again affected the propagation, the effect depending on the size and thickness of the discontinuities and the energy of the particles.

During the southern polar pass, where structures were present, we observed events with irregular time-intensity profiles, onset times and velocity dispersion modified by the presence or the lack of structures and discontinuities and field aligned flow. In between the shocks and discontinuities, the field tended to be relatively quiet and channeling could be observed. Occasionally, close to a boundary or interface, we observe a short period of non field-aligned flow. On the rare occasions in low-speed flow when no structures were present, we observed a smoother time-intensity profile, a rapid onset with velocity dispersion and moderately high field aligned anisotropies at the onset, diminishing with time.

During the highest latitude parts of the second polar pass, Ulysses was immersed in the fast solar wind. The fast solar wind tends mainly to be homogeneous, and devoid of large scale discontinuities, but is much more turbulent than the slow solar wind, and so particles propagate to high latitudes in high-speed solar wind with some difficulty. Energetic particle events observed during the part of the northern polar pass where Ulysses was at its highest latitude and in the fast solar wind had smooth time intensity profiles, near-isotropic particle angular distributions at all energies at the onset, flow directions during the rising phase of the events along the field, and no evidence for any net flow across the field lines. These particles propagated to the highest heliographic latitudes traveling along magnetic field lines and not across them.

Our observations do not allow us to draw conclusions about propagation closer to the Sun, but most likely, to reach the high latitudes, particles must either diffuse across field lines, most likely closer to the Sun, or else there was some large scale distortion of the magnetic field lines, again, closer to the Sun.

Finally we conclude with a summary table showing the energetic particle and the plasma characteristics of the two different high-latitude regions, the slow solar wind region observed during the second southern polar pass, and the fast solar wind region observed during second northern polar pass.

Acknowledgements

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Table 1. Summary of observations during the second polar passes

Characteristic	*Southern Polar Pass*	*Northern Polar Pass*
Solar wind	Slow	Fast
Time intensity profiles	Irregular	Smooth
Structures at onset	Frequent	Rare
Event onset times	Rapid	Delayed
High latitude Propagation	Modified by draping	Direct along field
Anisotropy at onsets	Large	Nearly isotropic
Particles inside CME	Intensities depressed	Intensities elevated
Particle flow directions	Field aligned	Field aligned (non-field aligned near structures)

References

Dalla, S., A. Balogh, S. Krucker, A. Posner, R. Mueller-Mellin, J. D. Anglin, M. Y. Hofer, R. G. Marsden, T. R. Sanderson, B. Heber, M. Zhang, and R. B. McKibben, Delay in solar energetic particle onsets at high heliographic latitudes, Annales Geophysicae, 21, 1367 - 1375, 2003a.

Dalla, S., A. Balogh, S. Krucker, A. Posner, R. Mueller-Mellin, J. D. Anglin, M. Y. Hofer, R. G. Marsden, T. R. Sanderson, C. Tranquille, B. Heber, M. Zhang, and R. B. McKibben, Properties of high heliolatitude solar energetic particle events and constraints on models of acceleration and propagation, Geophys. Res. Lett., 30, No. 19, 8035, 2003b.

Lario, D., R. B. Decker, E. C. Roelof, D. B. Reisenfeld, T. R. Sanderson, Low-energy particle response to CMEs during the Ulysses solar maximum northern polar passage, JGR, 109, A01108, 2004.

Marsden, R. G., Ulysses at Solar Maximum, in The Sun and the Heliosphere as an integrated system, IAU monograph, ed. G. Poletto and S.T. Suess, Kluwer, p113-146, 2004.

McKibben, R. B., J. J. Connell, C. Lopate, M. Zhang, J. D. Anglin, A. Balogh, S. Dalla, T. R. Sanderson, R. G. Marsden, M. Y. Hofer, H. Kunow, A. Posner, and B. Heber, Ulysses COSPIN Observations of Cosmic Rays and Solar Energetic Particles from the South Pole to the North Pole of the Sun during Solar Maximum, Ann. Geophys., 21, 1217, 2003.

Reisenfeld, D. B., J. T. Gosling, R. J. Forsyth, P. Riley, and O. C. St. Cyr, Properties of high-latitude CME-driven disturbances during Ulysses second northern polar passage, Geophys. Res. Lett., 30, No 19, 8031, 2003.

Sanderson, T. R., T. Appourchaux, J. T. Hoeksema, and K. L. Harvey, Observations of the Sun's Magnetic Field during the Recent Solar Maximum, J. Geophys. Res., No. A1, 1035, doi:10.1029/2002JA009388, 2003a.

Sanderson, T. R., R. G. Marsden, C. Tranquille, S. Dalla, R. J. Forsyth, J. T. Gosling, and R. B. McKibben, Propagation of energetic particles in high-latitude high-speed solar wind, Geophys. Res. Lett., 30(19), doi:10.1029/2003GL017306, 2003b.

Sanderson, T. R., Propagation of energetic particles to high latitudes, in The Sun and the Heliosphere as an integrated system, IAU monograph, ed. G. Poletto and S.T. Suess, Kluwer, 2004.

Suess, S. T., J. L. Phillips, D. J. McComas, B. E. Goldstein, M. Neugebauer, and S. Nerney, The Solar Wind - inner heliosphere. Space Science Reviews, 83, 75-86, 1998.

Zhang, M., R. B. McKibben, C. Lopate, J. R. Jokipii, J. Giacalone, M.-B. Kallenrode, and H. K. Rassoul, Ulysses observations of solar energetic particles from the July 14, 2000 event at high heliographic latitudes, J. Geophys. Res., 108, No. A4, 1154, doi: 0.1029/2002JA009531, 2003.

Discussion

Kahler: If it is possible to organize the observations by heliomagnetic coordinates, would we find that the SEP intensities vs time scales are also organized by heliographic latitudes?

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SANDERSON: Yes, I think there is one of the next steps for us with this data set. I would expect we will find some interesting correlations. I expect it will be relatively easy to do for solar minimum, but much more difficult for the most interesting solar maximum period.

SCHWENN: What is the present wisdom about energetic particles (CIR associated) at very high latitudes at activity minimum, although far away from the actual CIRs? Fisk or other?

SANDERSON: I think it is now time to re-examine this subject. During the second Ulysses orbit, a considerably greater number of CIRs with considerably higher intensity, were observed.

BOTHMER: 1) Comment on terminology: Dipolar /Quadrupolar /Multipolar structure
2) Drops in intensity of SEPs inside ICMEs just caused by background levels (higher in ecliptic than at higher latitude)?

SANDERSON: 1) The WSO data probably does not have enough resolution to show the multipolar structure. For this we should use some of the SoHo observations.
2) Background levels are so low that they do not influence the observations.

RUFFOLO: If I may ask you some basic solar physics in textbooks we read about the Babcock model of the 11-year solar cycle and magnetic reversals. However, this model still maintains basically a dipole field at all times, now you show us quadrupolar fields and how coronal holes evolve with the solar cycle. Do we need to revise the textbook explanation of magnetic reversals?

SANDERSON: The WSO observations cover more than a full 22year solar cycle. A comparison of the analysis with the Babcock and other models is beyond the scope of our analysis, but I would welcome some further interpretations by suitable theoreticians.

GOPALSWAMY: IP shocks observed at 1AU typically originate from anywhere on the disk. However, if they are accompanied by ICMEs, the source region is clustered around the disk center ($\pm$ 30° in lat. and long.). This makes me wonder if located beyond N75 can observe ejecta. Are the Ulysses plasma measurements consistent with CME? If so, may be the weak dipole field after reversal has allowed the CMEs to expand unusually to have a width $> 140°$.

SANDERSON: Surprisingly, CMEs have been observed up to these high latitudes. The CME presented here was identified on the basis of plasma observations by the Los Alamos group (Re. Serfeld et al. SW10, 2003). It was associated with a S16 flare. So far, 4 or perhaps 5 small CMEs have been identified, propagating in the fast solar wind. I would be interested to know if any of the models can reproduce these results.

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