SOLAR PARTICLES SEEN BY ULYSSES NEAR 33°S

S.J. TAPPIN and G.M. SIMNETT
School of Physics & Space Research, University of Birmingham, Birmingham, England.

Abstract. Observations of a particle event (electrons >40 keV; ions >50 keV) at heliographic mid-latitudes are presented. The particles are shown to originate from an apparently insignificant solar source and to be stored prior to release into the solar wind.

1. Introduction

¿From mid-July 1992 up to the south-polar pass, the low-energy particle environment at Ulysses has been dominated by ions and electrons accelerated by a corotating interaction region (CIR). In the events seen above ~25°S the ion fluxes consistently rise before the electrons (Simnett *et al.* 1995). The event starting on 21 June 1993 is unusual in that the electron fluxes rise first. Ulysses was at a heliocentric distance of 4.6 AU, a latitude of 33°S, 110°E of Earth, and was magnetically connected to ~30°W of central meridian.

Our observations were made using the HI-SCALE instrument (Lanzerotti *et al.* (1992)) on Ulysses. We use data from the LEMS30 aperture, which is at 30° to the Ulysses spin axis and covers electrons from 38-315 keV (DE 1-4) and ions from 56-4750 keV (P1-8). They are supplemented by plasma data from the SWOOPS instrument (Bame *et al.* 1992) and by information from Solar Geophysical Data (hereafter *SGD*).

2. Observations

The particle event which began on 21 June 1993 differed from the CIR events in that the electrons preceded the ions. From the interpretation of the CIR acceleration processes by Simnett & Roelof (1995) this is evidence that the electrons at least are not of CIR origin. Figure 1 shows the rise of the event in which several unusual features are present: **(1)** The ion fluxes show velocity dispersion with onset of the most energetic ions being 2–2$\frac{1}{2}$ days before the lowest energies. **(2)** A weak "pre-event" is seen in the lowest energy ions starting around the same time as the electron onset. This is similar to the "inter-events" discussed by Roelof *et al.* (1995), but with several differences. **(3)** The electron/ion ratio is higher than in any other event between the start of the CIRs and the disappearance of the CIR ions in early 1994. **(4)** The initial rise of the electron and high-energy ion fluxes was 7–8 days before the forward shock of the CIR at 1837 UT on 29 June (Balogh *et al.* 1995), compared with 1–2 days for the ions in other CIR events.

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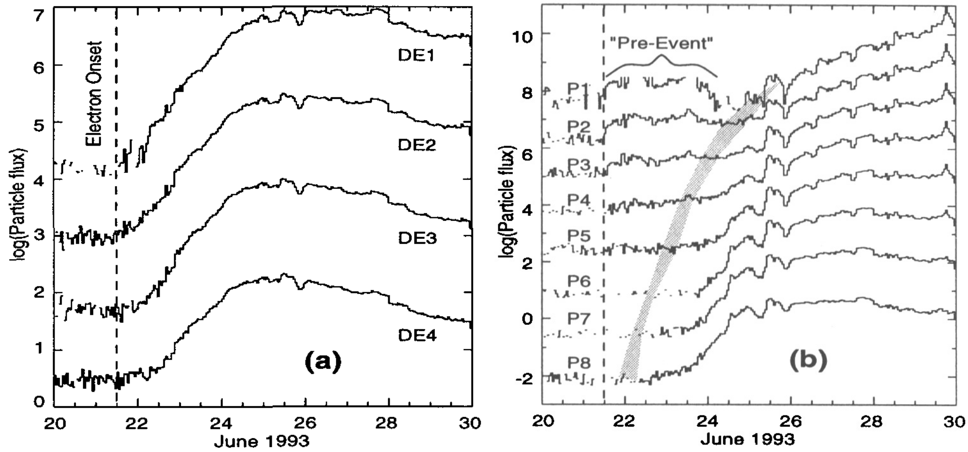

Fig. 1. The LEMS30 channels, plotted as 3-hour averages, for the interval 20-30 June 1993. (a) Electron Channels, (b) Ion Channels. Successive channels are offset by factors of 10. The shading in (b) indicates the earliest possible onsets of each channel.

The average solar wind speed during this interval was ~660 km s^{-1} which yields a spiral path from the Sun to Ulysses of 7.6 AU giving propagation times of 10-90 hours for ions and 1.5-3 hours for electrons. These propagation delays for the ions (from injection at 1000 UT on 21 June) are indicated by the shaded region in Fig. 1. The velocity dispersion in the onset of the ion fluxes is consistent with their being injected simultaneously with the electrons. But, the slow rise of both ions and electrons is inconsistent with all particles being injected impulsively at the base of the solar wind and propagating directly to Ulysses. This is easily seen qualitatively. Once the particles reach the field lines connecting to the spacecraft, they propagate almost scatter-free to Ulysses. For the first 6 hours of the event there was an ~40% excess in the antisunward electron flux. As the particles propagate in the diverging field lines they rapidly become field-aligned and thus, all particles of a given energy will arrive at the time for zero-pitch-angle particles, inconsistent with the 2-4 day rise-times seen in all channels. So the particles were either accelerated at the time of injection by a long-lived process, or else they were stored and released over a period of days.

The pre-event particles must have a separate origin as they do not have had time to propagate from the Sun to Ulysses from a common origin with the main event particles. They do not show velocity dispersion, suggesting that their arrival at Ulysses is spatial rather than temporal. The solar wind speed and connection longitudes show that during this onset and "pre-event", Ulysses was detecting a slowing of the solar wind. This is similar to the conditions associated with "inter-events" by Roelof *et al.* (1995). But

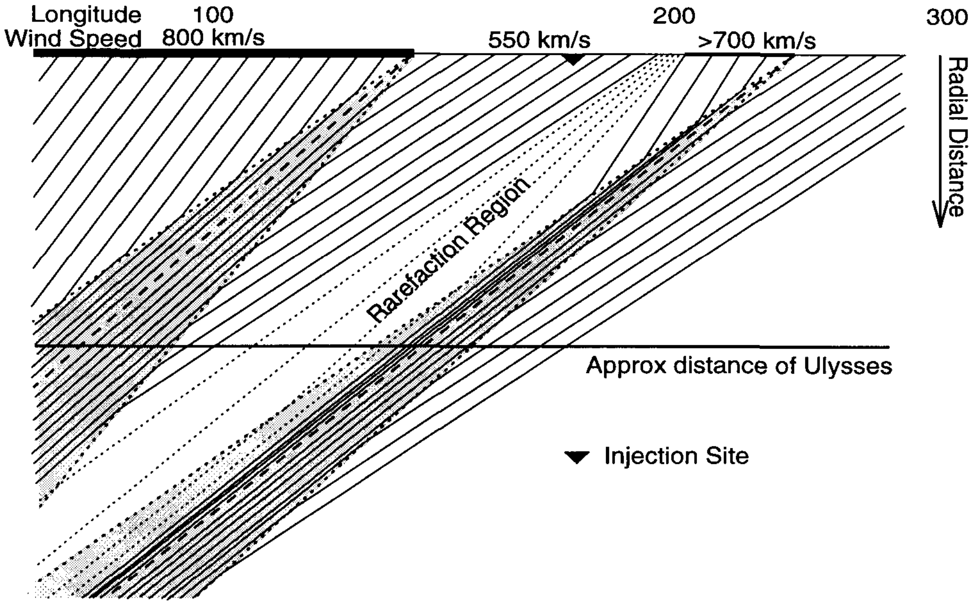

Fig. 2. Schematic diagram of the heliospheric topology for this event. The X-axis is Carrington longitude (not to scale) and the Y-axis is radial distance. The diagonal solid and dotted lines indicate field lines, the shaded areas are the interaction regions.

the "pre-event" peaked very soon after a velocity maximum at about 0700 on 22 June. There was also a density enhancement preceding this velocity peak, suggesting that a weak secondary stream passed over Ulysses.

3. Discussion

The time-histories of the particle fluxes require a sustained release at the base of the solar wind starting around 1000 UT on 21 June and lasting several days. So it seems probable that the particles seen prior to the beginning of 29 June were accelerated in the low corona where they were not able to escape immediately. The particles diffused from this region, onto the open field lines of the rarefaction behind the minor fast stream at a rate independent of energy and species (Simnett 1995). If this escape occurs on a timescale of a few days, this explains consistently the observed electrons and time-dispersed ions. This can be visualised with the aid of the solar wind topology shown in Fig. 2. From this we can estimate the likely acceleration site. For topological reasons, it must be between the two fast streams, at a Carrington longitude between 150° and 200°. Since the time from the start of the escape to its maximum rate was about 3 days, the acceleration probably occurred of the order of days prior to the first particles reaching the open field lines. As this makes the acceleration site visible from Earth (longitude 200° was at CMP on 19 June), we should be able to identify the actual event which generated these particles. None of the observations reported in *SGD* have a suitably-placed **strong** event. However the Nançay Radioheliograph detected an event at 1120 UT on 20 June a few arcmin SW of disk centre, close to the expected source location. This is the site of the newly-emerged AR7525 and of a bright feature on the Yohkoh image in *SGD* on 20 June. The event is too small to be the source of a major particle event, but in the absence of any other plausible origins within the time interval in which we believe the acceleration occurred it seems likely to be the particle source. We may well be witnessing the result of magnetic reconnection in the high latitude corona, where the local field topology does not naturally guide the particles into the chromosphere. Thus coronal (radio) and interplanetary signatures are seen, without anything significant in the chromosphere.

This model does not account for the "pre-event" low-energy ions, which reach Ulysses as a result of the spacecraft entering a region where they were already present. A probable explanation of these ions is that they were accelerated by the secondary stream.

4. Summary

We have identified the arrival of solar energetic particles at Ulysses at mid-latitudes and large radial distance. A plausible solar origin of these particles is in a minor flare associated with a newly emerged active region. We have also demonstrated the need for the particles to be stored in the solar corona prior to their escape into the outer heliosphere.

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References

Bame, S.J., *et al.*: 1992, *Astron. Astrophys., Suppl.* **92**, 221
Balogh, A., *et al.*: 1995, *Spa. Sci. Rev.* **72**, 171
Lanzerotti, L.J., *et al.*: 1992, *Astron. Astrophys., Suppl.* **92**, 349
Simnett, G.M., Sayle, K.A., Tappin, S.J. and Roelof, E.C.: 1995, *Spa. Sci. Rev.* **72**, 327
Simnett, G.M. and Roelof, E.C.: 1995, *Spa. Sci. Rev.* **72**, 303
Roelof, E.C., Simnett, G.M. and Armstrong, T.P.: 1995, *Spa. Sci. Rev.* **72**, 309
Simnett, G.M.: 1995, *Advances in Space Research*, Vol. **14** (in press).
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