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Time scales of solar energetic particle events and solar wind stream types

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Abstract: The onsets, rise times, and durations of solar energetic particle (SEP) events observed at 1 AU vary considerably, even for events from comparable solar longitudes. Does the ambient solar wind (SW) stream play any role in those variations? In an earlier study (Kahler, 2005), times from CME launch to event onset, rise times, and durations of 20 MeV solar proton events observed on the Wind spacecraft during 1998-2002 were compared with ambient SW O+7/O+6 values to search for correlations with SW stream types. Here we compare those timescales for the same events with their associated SW components classified as transient structures, high-speed streams, and slow wind by Cane and Richardson (2003). The SEP events are further sorted into five groups of solar source longitudes to compensate for well known variations of timescales with connection longitudes. We find only a slight trend for the shortest timescales in transient structures, but otherwise no dependence of any time scales on SW stream type. In particular, there is no evidence for enhanced convective and adiabatic energy losses in low speed streams or for enhanced scattering in high speed streams.

Introduction

Early attempts to understand the solar injection and propagation of E $>$ 10 MeV SEPs based on their event timing characteristics were carried out by Reinhard and Wibberenz (1974) and van Hollebeke et al. (1975). They considered the time intervals from SEP acceleration at the Sun to peak SEP intensities at 1 AU. The strong dependence on solar magnetic-connection longitudes and on shock propagation was the basis of the qualitative model of SEP intensity profiles by Cane et al. (1988). Recently, Kahler (2005) analyzed the statistics of SEP event timescales based on intensity-time profiles for 144 E = 20 MeV SEP events observed by the EPACT experiment on the $Wind$ spacecraft. For comparisons with associated CME and SW properties, three characteristic times, shown in Figure 1, were measured for each event and listed in a table. T_O is the time from launch of the associated coronal mass ejection (CME) to SEP onset at 1 AU; T_R is the time from SEP onset to the time the SEP intensity reached half the peak value; and T_D is the time during which the SEP intensity was within a factor of 2 of the peak value. Only weak correlations of T_R and T_D with CME widths and speeds were found.

Kahler (2005) also looked for any role the SW structure might play in the SEP characteristic times. For that purpose he used the SW O+7/O+6 values measured on the ACE spacecraft, where fast SW streams were identified by O+7/O+6 $<$ 0.15 (Zurbuchen et al., 2002). No correlations of any SEP characteristic times with the O+7/O+6 ratios were found, and Kahler (2005) concluded that the SEP event times are independent of the type of SW stream. He also looked separately at the SEP event times that occurred within interplanetary CMEs (ICMEs) using a list of ICMEs published by Cane and Richardson (2003). All three characteristic times were slightly shorter for those events than for the total population of SEP times. It would be useful to re-examine these results with the SW data organized or sorted by criteria other than the O+7/O+6 ratios.

Richardson et al. (2002) have considered the contribution of different SW stream types to long-term ($\geq$ solar rotation period) averages of geomagnetic activity and the interplanetary magnetic field (IMF) strength. In particular, they used several criteria to divide the SW into three

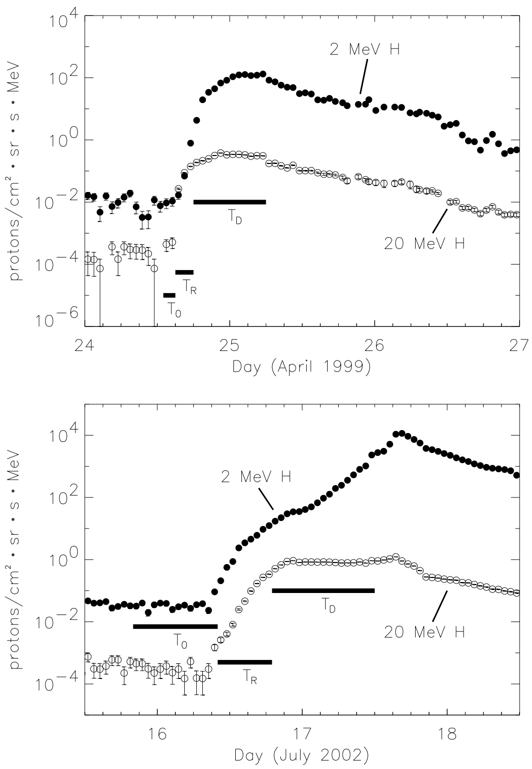

Figure 1: Plot of 2 and 20 MeV proton intensities from the EPACT instrument on Wind during the SEP events of 1999 April 24 and 2002 July 16 (from Kahler, 2005). Horizontal bars show the periods of the three SEP times of the 20 MeV protons used in the study - T_O, T_R, and T_D. The time of the CME launch matches the beginning of the T_O interval and was an extrapolation of the CME height-time profile to 1 Rs.

components: (1) transients, consisting of interplanetary CMEs (ICMEs), shocks and postshock flows; (2) corotating high-speed streams; and (3) slow SW. The three-component SW-classification scheme has been updated through 2005 (Richardson, private communication, 2007), and we use it here to look for any dependence of the SEP-event characteristic times on those three SW types. It is important to note that component (1) above includes time periods beyond the ICME intervals published in Cane and Richardson (2003).

Data analysis and results

We first assign a SW stream category to each of the three SEP event times given in Table 1 of Kahler (2005). If a time period overlapped two SW stream types, we used the type with the longer association. We eliminated the 2001 August 15 SEP event, which probably had an incorrect solar source longitude (Cliver et al., 2005). We follow the procedure of Kahler (2005) to sort the 143 SEP event sources into five longitude bins: (1) east limb to central meridian; (2) W01^o to W31^o; (3) W32^o to W62^o; (4) W65^o to W90^o, and (5) over the west limb. These five groups, each of $\sim$ 30 events, allow us to compensate somewhat for the known dependence of SEP times on solar source longitudes. The median times for each timescale (T_O, T_R, or T_D) are shown in Figure 2, sorted by type of SW stream (1, 2, or 3), and solar longitude bin. Each data point is the median of about 10 events, whose values are generally equally distributed in intervals of log T_X. We state the median values to a precision of 0.1 hours, but the probable error for each time in the figure is roughly a factor of 2.

Conclusions

Onsets and Rise Phases

The dynamic range of each of the three SEP event timescales considered here is more than an order of magnitude (Kahler, 2005). The intensity-time profile of a SEP event measured at 1 AU is determined by the injection profile from the CME-driven shock and by the SEP propagation characteristics in the SW stream. The object of the current analysis is to determine whether the SEP-event timescale variations can be attributed to or organized by the different kinds of SW streams. Kahler (2005) used SW O+6/O+7 ratios for this test and found no timescale dependencies. Here we use an alternative SW signature but obtain the same result: there is no clear timescale dependence on the SW type. In particular, the larger sample of ICME flows (group 1) supports the result of Kahler (2005) that the timescales are only slightly, but not significantly, shorter in those SW streams. The implication is that the timescale variations must be attributed primarily to variations in the injection profiles near

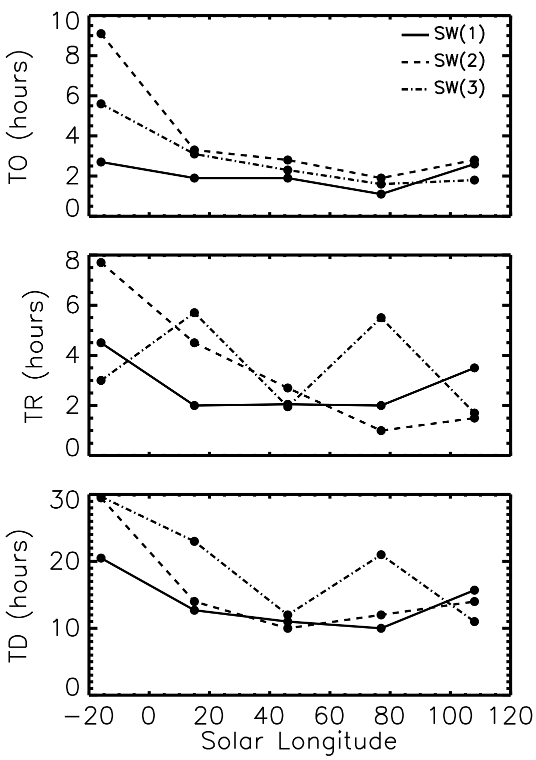

Figure 2: Plots of the SEP event timescales T_O, T_R, and T_D for each of the three SW stream types [(1) - transient; (2) - fast; (3) - slow]. Each data point is the median value of all events in that solar longitude range.

the Sun. This means that spatial and temporal variations in seed populations, shock geometries and compression ratios, magnetic field intensities and topologies, and plasma densities near the Sun determine the variations we see at 1 AU. If we take $T_O + T_R < 8$ hours, then for a fast CME of $\sim$ 1000 km/s ($\sim$ 5 Rs/hr) driving a shock, the primary SEP injection from the preceding shock occurs < 50 Rs.

Decay Phases

Gradual SEP event durations as functions of solar connection longitudes were analyzed by Dalla (2002), who found that the durations, defined as times the $28 < E < 36$ MeV proton intensities were above background levels, ranged over an order of magnitude and generally declined with better magnetic connection, in qualitative agreement with our values of T_D in the bottom panel of Figure 2. It is perhaps not surprising that SW-stream differences are not important for T_O or T_R, but SEP event decays are considered to be controlled at least partly by SW flows. If we assume that shock SEP injection has ceased and the shock structure is not modulating the decay phase, then the exponential decay times τ_e, due only to convection and adiabatic energy loss, should scale as $1/V(1+\gamma)$ (Daibog et al., 2005), where V is the solar wind speed and γ the exponent of the SEP power-law energy spectrum. Looking at τ_e for only low ($\sim$ 3 MeV) energy proton events at 1 AU, Daibog et al. (2005) found that about half their 146 event decays were fitted within 25% by the value of τ_e calculated with the $1/V(1+\gamma)$ term, indicating that τ_e decreases with increasing V, although not necessarily linearly with V. For our study this would imply smaller values of T_D for the SW group 2, which we do not find. However, we have to remember that our definition of T_D is the time during which the SEP intensity is within a factor of 2 of the peak value, and this may not reflect or correlate with τ_e, which could be measured at much later times.

In contrast to the Daibog et al. (2005) result, Sanderson (2004) found that durations of SEP events in fast SW were longer ($\sim$ 15 days) than those observed in slow SW ($\sim$ 7-10 days). His result was based on observations during the second polar pass of *Ulysses*, which included only four large 1 MeV $< E <$ 100 MeV SEP events in fast SW. He argued that SEP events in fast SW should have longer timescales, as observed, because the magnetic fields are more turbulent in fast SW than in slow SW. This argument implies that the SEP event durations are due primarily to particle scattering, and not to convective or adiabatic energy losses. As with the Daibog et al. (2005) result, it is not obvious that the total durations Sanderson (2004) was describing are directly comparable with our parameter T_D.

Another way in which τ_e could be modulated by the SW is through the compression or expansion of large-scale magnetic fields in periods of steadily increasing or decreasing V, respectively. Sarris and Malandraki (2003) compared values of τ_e for two $E > 50$ keV electron events, and found τ_e longer for the event in a converging flow than the one in a diverging flow. They suggested that the converging SW flows could provide magnetic barriers beyond 1 AU to retard the decays of SEP events and establish the particle reservoirs (Roeloff et al., 1992) following some SEP events. However, in their analysis of the E $\sim$ 3 MeV proton events, Daibog et al. (2005) found the opposite case, that τ_e averaged 19.1 hours for 77 cases of monotonically decreasing V and 16.5 hours for 20 cases with monotonically increasing V. We compared our event parameter T_D with the SW stream interaction times selected on the bases of increasing SW speeds and peaks in the perpendicular SW pressures (Jian et al., 2006). Only 12 of the 135 T_D intervals lay totally or mostly within such streams, but they were generally comparable to or slightly smaller than the remaining values, a result consistent with that of Daibog et al. (2005). This suggests that the magnetic geometry of the large-scale SW field has negligible affect on SEP durations or decays.

Acknowledgements

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