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Solar impulsive electron events with unusual velocity dispersion

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Abstract. A statistical survey of 26 solar impulsive electron events in the ∼1 to 300 keV range is presented, as observed by the 3D Plasma and Energetic Particle experiment on the Wind spacecraft. This study was triggered by results of ACE/EPAM observations (Roelof et al.) reporting the absence of velocity dispersion in solar energetic electrons events in the energy range of 40-300 keV. Earlier studies also reported the absence of dispersion in some events, whereas Roelof et al. claim to see no velocity dispersion in most of the events. The presented survey in this paper shows that besides normal dispersive events (14 out of 26), there are indeed events with unusual velocity dispersion (12 out of 26) showing nearly simultaneous onsets at 1 AU above 100 keV. A strong correlation between the peak flux and the absence of velocity dispersion is found: Events with high peak flux ($\geq$0.2 cm^{-2}s^{-1}ster^{-1} eV^{-1} at 27 keV) show unusual velocity dispersion. This explains that earlier WIND/3DP surveys taken during solar minimum where events were smaller did not show events with unusual velocity dispersion.

1 Introduction

Solar impulsive electron events observed in interplanetary space near 1 AU generally show velocity dispersion in their onsets normally produced by the difference in time of flight of electrons at different energies. Recent results of ACE/EPAM observations report that the onset at 1 AU in the energy range from 40 to 300 keV is nearly simultaneous (Roelof et al. 2000). Hence, these events show no velocity dispersion. The absence of velocity dispersion in implusive electron events was reported earlier too (e.g. Lin et al. 1985, Krucker et al. 1999), however, the reported number of dispersive events was much larger. The sudden onset at several energies in dispersive-free events was thought to be produced by the spacecraft motion crossing boundaries of spatial structures, as also detected in proton events (Mazur et al. 2000). Roelof et al. favor the idea that the electrons experience strong wave-particle slowing down the electron. The slowing down than works against the time of flight difference and makes the velocity dispersion disapear. This paper tries to understand the discrepancies between the reported number of dispersive and dispersion-free events.

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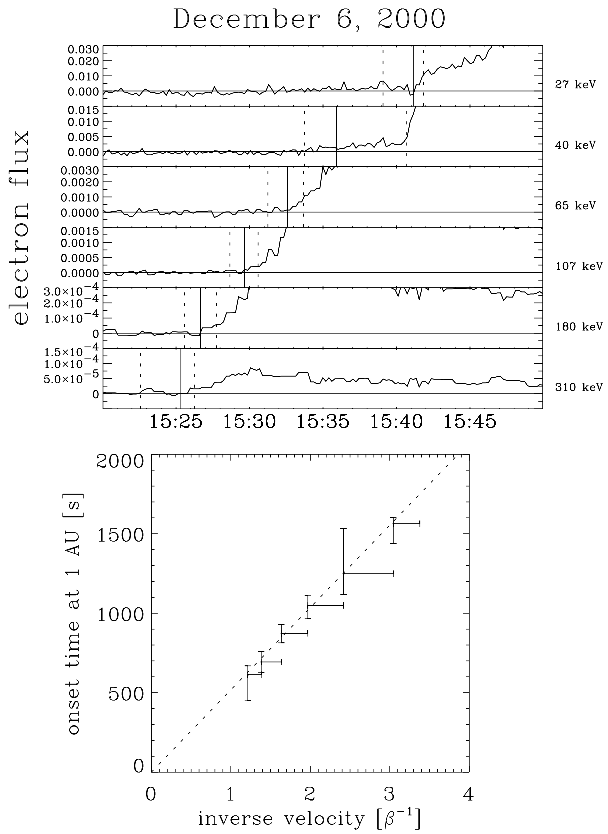

Fig. 1. An event with clear velocity dispersion. The top panels show the background subtracted time profiles of the electron flux for different energies as indicated. The approximated onset times are marked. The dotted lines give conservative upper and lower limits. Below the onset times are shown as a function of inverse velocity. The dotted line is a linear fit to the observed onset times.

2 Observations

The presented survey was selected from events occurring in 2000 detected by the WIND/3DP solid state telescopes (Lin

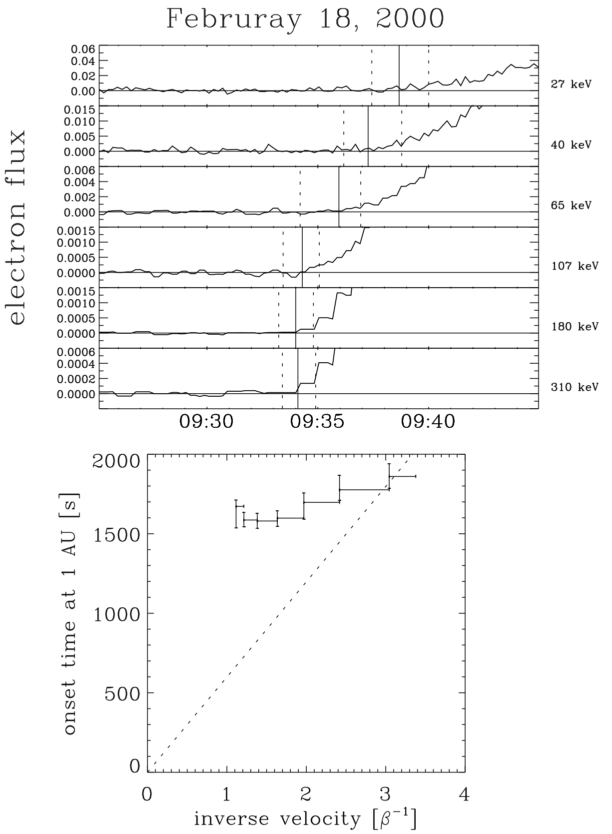

Fig. 2. Same as Figure 1 for an event with an unusual velocity dispersion. The dotted line in the bottom panel give the expected onset times assuming the electrons travel scatter-free along the Parker spiral.

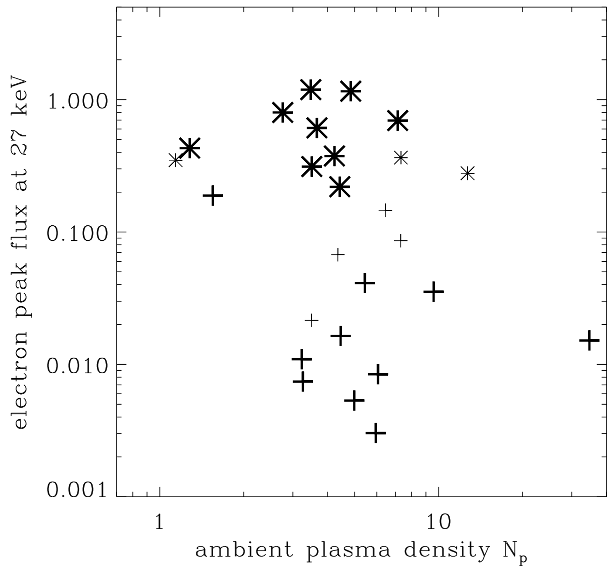

Fig. 3. The peak flux in $cm^{-2}s^{-1}ster^{-1}$ eV^{-1} at 27 keV vs. the ambient plasma density is shown. Dispersive events and events with unusual dispersion are distinguished by pluses and stars. Questionable events are printed smaller. There is a clear correlation between the different events and the peak flux, but no correlation with the ambient plasma density.

et al. 1994) in the energy range of 30 keV to 300 keV. To compare with ACE/EPAM observation, only events seen up to 300 keV were selected. Form the total number of about ∼100 events seen above 30 keV, only 30 events are clearly seen above 300 keV. Out of these 30 events, 4 do not show clear onsets. For the remaining 26 events the onset times where determined by hand as described in Krucker et al. (1999).

14 out of these 26 events show a clear velocity dispersion. An example of a dispersive event is shown in Figure 1. The linear fit to the onset times at 1 AU as a function of inverse velocity gives a path length of about 1.25+-0.08 AU, similar to what is expected from the Parker spiral length (1.20 AU).

The other 12 events do not show the expected velocity dispersion. Figure 2 shows an example of an event with unusual dispersion. Above ∼100 keV the onsets are simultaneously within the uncertainties. The onset times between 65 keV and 27 keV show a weak dispersion, much less than what is expect from the difference in time of flight at these energies (dotted line in bottom panel of Figure 2). The dispersion does not seem to be totally absence at energies between 30 keV and 100 keV. These events might be better described as events with unusual velocity dispersion than as dispersion-free events. For some of the events, the derived onset times have larger uncertainties than the examples show in Figure 1&2. Therefore the onset times are not always clear: 4 of the 14 dispersive events and for 3 out the 12 events with an unusual dispersion are questionable cases.

2.1 Correlation

Several parameters were check for correlation to outline dispersive events and events with unusual dispersion: the electron peak flux, the spectral index, the pitch angle distribution, and several plasma parameters observed at 1 AU such as ambient plasma density, magnetic field strength, plasma temperature, and solar wind speed. Only the electron peak flux shows a correlation (Figure 3): Only large events (≥0.2 $cm^{-2}s^{-1}ster^{-1}$ eV^{-1} at 27 keV) show unusual dispersion.

2.2 What is seen at lower energies?

The energy range below 30 keV is covered by an electron electrostatic analyzer (EESA-H). Despite the larger uncertainties in the onset times derived from the electrostatic analyzer, the onset times at 1-15 keV clearly show that at lower energies all events show velocity dispersion (Figure 4&5). The path lenghts derived from the 1-15 keV onsets are about what is expected from a Parker spiral.

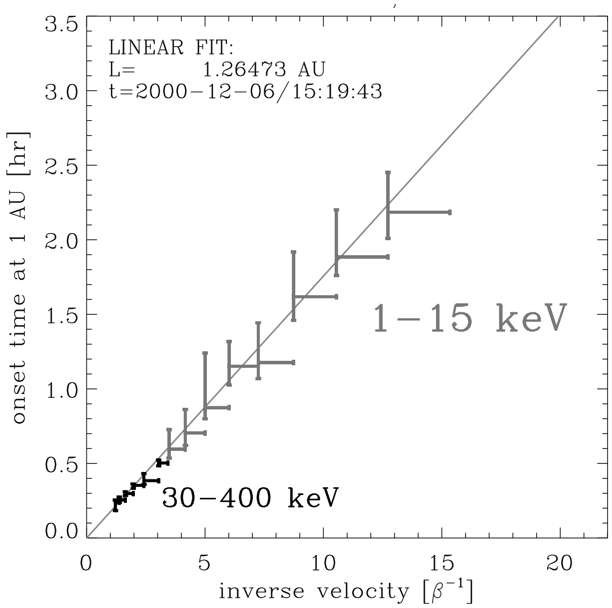

Fig. 4. Onset times at lower energies: Dispersive events at 30-300 keV also show dispersion at lower energies. The gray line is a linear fit to the 1-400 keV onset times.

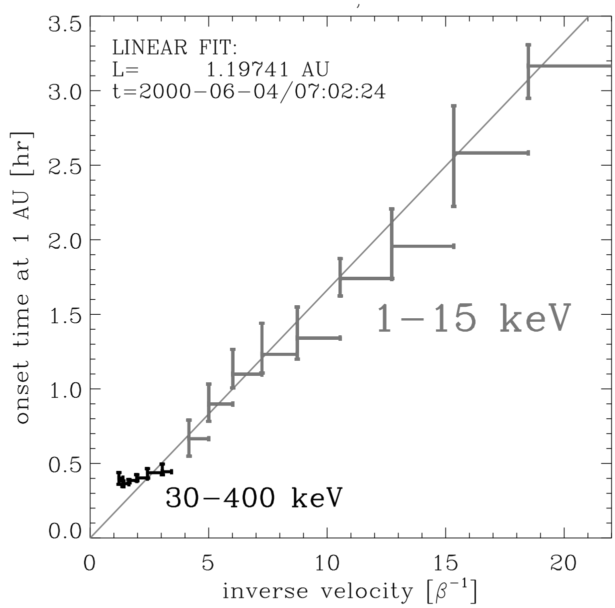

Fig. 5. Onset times at lower energies for an event with unusual dispersion above 30 keV: At lower energies, all events show dispersion. The gray line is a linear fit to the 1-15 keV data only.

3 Discussion

The correlation that only large events show unusual velocity dispersion at high energies explains the different numbers of reported events with unusual dispersion: Around solar minimum intense events with unusual dispersion are rare. Therefore, the survey by Krucker et al. (1999) of events from 1994 to 1997 did not report them. On the other hand, Roelof et al. are analyzing data from the ACE spacecraft that is operational since late 1997. Compared to the total number of impulsive electron events (∼100 events above 27 keV), only the strongest 10 to 15% show an unusual velocity dispersion.
How can the unusual velocity dispersion be explained? If only one population of electron is released, then the unusual dispersion means that ≥100 keV electrons are arriving too late at the spacecraft. Figure 5 shows that 300 keV electrons arrive at the time when ∼50 keV are expected to arrive.
One way to explain this is if a second process later accelerates electrons to higher energies where the low energy electrons are the seed population. The time it needs to accelerate electrons to higher and higher energies might cause the unusual velocity dispersion. The correlation with high peak flux (Figure 3) would then say that only the second acceleration process is efficient enough to produce large fluxes at high energies.
Assuming only one electron population, wave-particle interaction would not explain the observed onset times. Wave-particle interaction slows down electrons. Hence, an arriving electron at 300 keV had initially an even higher energy. Electrons experiencing wave-particle interaction should therefore arriving earlier at 1 AU than what is expected from the time of flight. However, under the assumption that there is only one electron population, ≥100 keV electron are observed to arrive late.
If wave-particle interactions are involved in causing the unusual velocity dispersion, then the observed onset times of these events say that there are two different electron populations accelerated at the Sun: (1) a low energy (≥1 keV) population released first, and (2) a second population at higher energies (≥30 keV) released about 10-20 minutes later. The second population experiences wave-particle interactions, causing the unusual velocity dispersion observed at 1 AU. Assuming that there are two separated populations of electrons, however, the unusual velocity dispersion can also be explained if the second population has an energy dependent acceleration/release mechanism, and no wave-particle interaction is needed. The correlation with high peak flux (Figure 3) would again say that the second acceleration process is more efficient at high energies than the first one.

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References

Krucker, S., Larson, D. E., Lin, R. P., & Thompson, B. J., 1999, ApJ, 519, 864
Lin, R. P., 1985, Sol. Phys., 100, 537
Lin, R. P. et al., 1995, Space Sci. Rev., 71, 125
Mazur, J. E et al., 2000, ApJ, 532, 79
Roelof, E. C. et al., 2000, spring & fall AGU