Are STEREO single hits dust impacts?

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Some of the waveforms returned by the TDS part of the Swaves experiment on the two STEREO spacecraft show a very large signal on only one antenna, with signals smaller by a large factor on the other two. Although this could happen for a single event, the large signal is always on the same antenna, the X antenna for STEREO B and the Z antenna for STEREO A.

The smaller signals are of the same sign as the large one.

There are other peculiarities of these single hit events that do not seem compatible with nearly random impacts by dust particles.

$$\frac{d(mv)}{dt} = -A\rho_T v^2$$

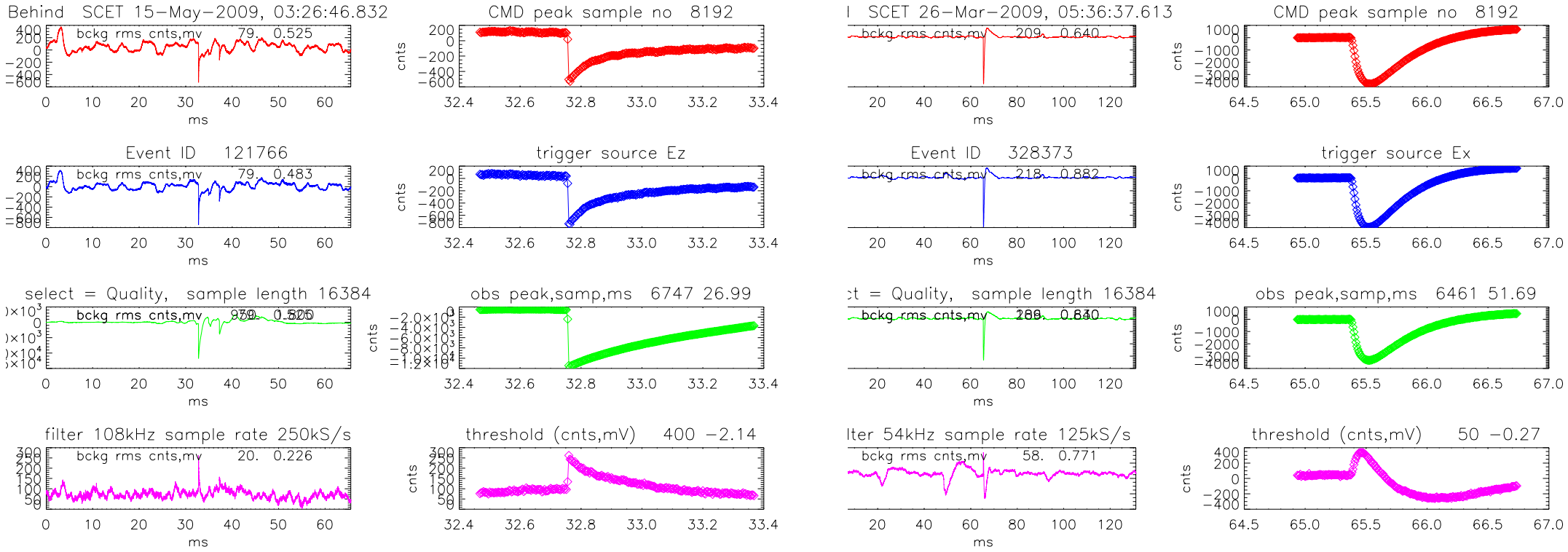
(1) The numbers of single hit impacts on the two spacecraft are different by an amount which is beyond statistical fluctuation, namely 157826 (A) and 50088 (B) for the period 2007-2010 (Zaslavsky et al 2012).

(2) Single hit events on STEREO A essentially stopped in early 2011 although they continued on STEREO B for 3 ½ more years until it passed behind the sun in Sep 2014.

Early on, there was much uncertainty in the community as to whether all these impulses were really dust, or whether they were some impulsive interference. People kept asking me if such events were seen with the similar experiment on Wind.
The results of an examination of the Wind data have been published (Kellogg et al 2016). In this work, an attempt was made to distinguish nanodust, small dust particles entrained by the solar wind, from what is essentially the zodiacal light cloud, and interplanetary dust, by measuring the risetime of the recorded pulses. This is not as good a way to distinguish fast dust as could be desired, as laboratory measurements have shown that the temperature of impact clouds and therefor rise speed vary only as the square root of the impact speed.

At any rate, no unusually fast rising pulses were found. Further, many fewer pulses were found in the Wind data than the number of one hits on STEREO. So we were unable to confirm the STEREO interpretation of one hits.

The shape of the one hits is different from that of triple hits. Below are shown examples, chosen to not be very saturated. The triple hits (right) have a rounded top and a rise slower than that of the one hits (left). Note that these are ”raw” data to assist in identification of saturation and are inverted from the physical voltage. Saturation occurs for “raw” = 32768 and V about 160 mV.



S_nano_search2_plot.ps, from S_nano_Search2, version 25−Oct_2017, output at Mon Oct 30 14:46:58 2017

_search2_plot.ps, from S_nano_Search2, version 25−Oct_2017, output at Mon Oct 30 14:42:10 2017

The acceleration by interaction with solar wind electric fields has been calculated and reported in several papers by Mann and Czechowski
(e.g. Mann et al, 2014, Czechowski and Mann)

In order to be accelerated to 150 or 300 km/s the particles must be fairly small. For acceleration to 300 km/s, the ratio of charge to mass must be about 10^{-5} e/ m_p and to 150 m/s. about 10^{-6} e/ m_p respectively
where e is the electron charge and m_p is the mass of the proton.

As to be shown, these masses can generate only reasonably sized charges, not quite enough to saturate STEREO TDS measurements. However, the calculations have a large uncertainty, due to using the calibrations of Collette et al for a velocity range well outside the measurement range, and even in the measurement range there is a lot of variation in the measurements.

Many of the single hit signals are huge. Zaslavsky et al (2012) eliminated saturated events from their analysis, but their size can be seen from the length of the saturated part of the signal.

The mass and charge on a dust particle is calculated as follows. Czechowski and Mann have calculated the acceleration for various charge to mass ratios. Such calculations have been done for acceleration at 1 AU and up to 2 AU, but I have not found any calculations as far as Saturn. Below is from Mann, Meyer-Vernet and Czechowski, Physics Reports, 2014.

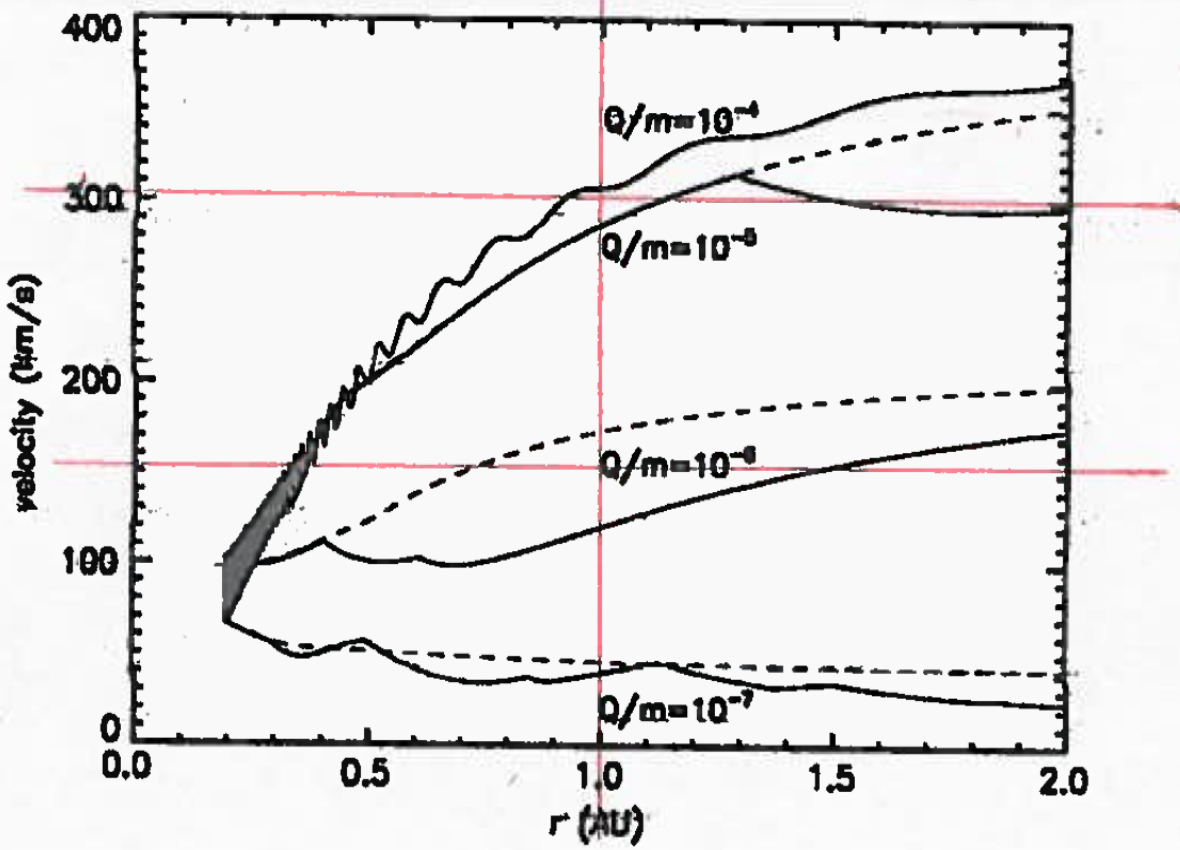


Fig. 21. Velocity plotted against the distance from the Sun for the grains with $q_d/m = 10^{-4}$, 10^{-5}, 10^{-6}, and 10^{-7} e/m_p released from a circular orbit with the radius 0.2 AU near the ecliptic. Solid lines correspond to the focusing and dashed to defocusing magnetic field orientation.

So what is the mass of a particle that can be accelerated to 300 (or 150) km/s, and what is the charge emitted when it strikes a target?

From Mann et al (2014) and their other calculations, we have that particles capable of acceleration to 300 and 150 have Q/m = 10-6 and 10-5 e/m_p respectively. Using:

$$V = Q/4 \pi \varepsilon_0 R , \quad m = 4 \pi/3 \rho_D R^3, \quad Q/m = F\, e/m_P$$

Where Q and R are the charge and radius of the grain, ρ_D is its density and e and m_P are the electron charge and mass of the proton. F is 10^{-5} and 10^{-6} for acceleration to 300 and 150 km/s respectively.

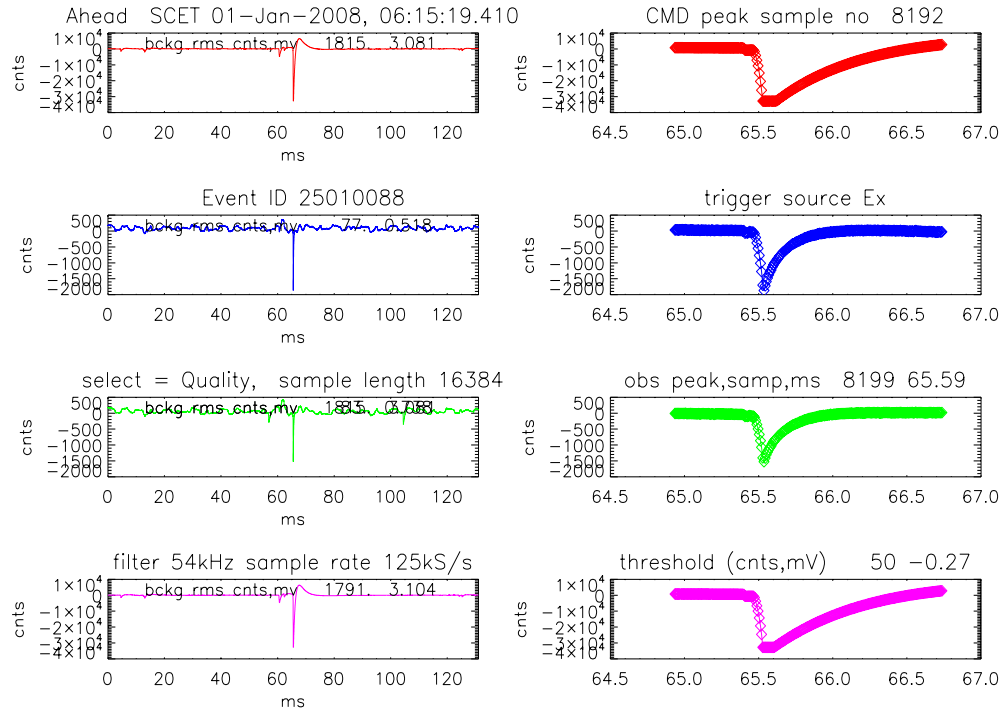
We obtain:

$$m^2 = (3/(4 \pi \rho_D)) (4 \pi \varepsilon_0 m_P V/ F e)^3$$

Giving $m = 2.5\ 10^{-22}$ kg for the 300 km/s grain and $7.9\ 10^{-21}$ kg for 150 km/s

Using the Colette et al calibration of emitted charge as a function of particle mass and Impact speed, this leads to an emitted charge of about 3.9 10^{-11} C for multilayer Insulation and about 12 10^{-11} C for kapton which will make a voltage of about 90 mV for MLI or about 45 mV on an antenna allowing for a gain of ½, and 3 times more for Kapton. The emitted charge for the antenna material, BeCu, is quite a bit smaller.

Below is shown a moderately large one hit event. It was chosen because only the X antenna, which is where all the one hits occur on STEREO A, is only slightly saturated, at about 160 mV, and the others are not. There are many bigger one hits where all three antennas show some saturation.



Ahead S_nano_search2_plot.ps, from S_nano_Search2, version 25−Oct_2017, output at Wed Nov 1 19:39:28 2017

Zaslavsky et al (2012) proposed an ingeneous process suggested in two papers by Pantellini et al, to increase the size of signals. It involves weak fields that change the angular momentum of photoelectrons so that they do not return to their antenna and leave it more positively charged, Kellogg [2016) did some calculations of these orbits and found that there is a threshold for the effect, in that, because the STEREO antennas are thick, an appreciable field is necessary to change the angular momentum enough to miss the antenna, especially on the second orbit. It seems that this process would not be sufficiently effective to account for the very large signals.

SUMMARY

One hits are found on only one antenna, always the same on a given spacecraft. Hits at random places on the spacecraft would give signals on the nearest antenna and probably on all.

The number of one hits on A and B are not the same and differ by much more than the statistical error.

The numbers of triple hits on STEREO are roughly in agreement with the number on Wind but the number of one hits on STEREO is an order of magnitude higher. (Note the the number of triple hits on STEREO is somewhat smaller than Wind, which we attribute to difference in saturation level.)

No corresponding signals were found on Wind, though signals corresponding to triple hits were found in numbers and behavior which was consistent with expectations.

The shape of the one hit signals is different from that of triple hit signals. Instead of some gradual changes which can be attributed to the motions of an ion cloud emitted by the impact, the increase of potential is so rapid as to be consistent with instantaneous change modulated by the frequency response of the electronics.

The signals have all the characteristics of sudden charge increase on the given antenna, with restoration to normal potential very like that of three hit events, which have proper characteristics for genuine dust hits. The time sequence of this restoration have been nicely calculated by Zaslavsky (2016) and corresponds to known physics. These signals also appear in other systems of STEREO SWaves such as the radio systems, indicating that they are actually signals on the antennas and not spurious signals generated by the electronics. (However there is a small section of the electronics which is common to most of the systems).

On STEREO they are very large, often saturated at more than 150 mV.

It is my belief that one hits are not dust impacts. It follows that there is no evidence in the STEREO data, nor in any other experiment using antenna signals to detect nanodust, for a reliable flux of nanodust accelerated by entrapment in the solar wind.

Note also that there is no evidence at all that nanodust does not exist. It is only that this very nice picture of detection is suspect.

Speculation

What can cause sudden charging of an antenna?
Stuart Bale and Keith Goetz, who are most familiar with the antenna mechanism, have pondered this question and have seen that there is pretty much only one structure touching the antennas, the Dacron cord inside the antenna which regulates the rate of deployment. How does it get charged? Keith thinks that it might be charged by electrons from cosmic ray penetration of the antenna.
My suggestion is that it is charged by friction with the interior of the antenna. As the antennas are probably not exactly straight because they are heated by the sun on one side, it is likely that the cord rubs on the inside of the antenna. I suppose this rubbing could change when the thrusters or reaction wheels change the spin slightly.

Future.

If one hits are spurious and are not nanodust, then how can nanodust be distinguished?

TDS does not measure velocity directly, but there should be some information in the rise time of the signals, and perhaps someone can think of another characteristic that is revealing.

Aside from other experiments that do measure the velocity, I can see that more careful measurement and understanding of rise time provides the only hope.

I am starting to look at hits on the antennas themselves, which are of the order of 10% of the triple hits. Whereas the rise time of hits on the spacecraft, if it is due to progress of the cloud through the photoelectric layer and electron stripping, will vary as that layer is not the same around the spacecraft, the field around the antennas is the same for all and relatively constant.